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14. ABSTRACT
During the reporting period we focused on conducting an error analysis of students' game play data and redesigning the game levels based on the types of errors students were making. The error analysis examined students' step-by-step process of simplifying exponent expressions. The majority of errors were related to the misapplication of the power rule, incorrect transformation between exponent and root forms, apparent confusion involving the negative sign and expressions raised to a power, and the misapplication of the negative exponent rule. These errors were the basis for redesigning the game levels and assessments.

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Report Title

Final Report: Using Game Play to Diagnose and Remediate Students' Misconceptions in Solving Equations

ABSTRACT

During the reporting period we focused on conducting an error analysis of students' game play data and redesigning the game levels based on the types of errors students were making. The error analysis examined students' step-by-step process of simplifying exponent expressions. The majority of errors were related to the misapplication of the power rule, incorrect transformation between exponent and root forms, apparent confusion involving the negative sign and expressions raised to a power, and the misapplication of the negative exponent rule. These errors were the basis for redesigning the game levels and assessments.

The new game level design focuses on (a) exponent to root transformations, (b) the negative exponent rule, and (c) the power rule. Sets of game levels have been designed to structure game play to emphasize varied practice and reflection. The revised design also includes a self-explanation prompt to emphasize reflection and a challenge problem that gives students only a single chance to solve the problem (which also serves as an in-game measure of learning).

Next steps include implementing the revised game design and updating the pretest and post-test to match the game levels, gathering data on the revised game, and publishing the work in a book chapter.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

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Number of Manuscripts:

Books

Received	Book

TOTAL:

Received	Book Chapter

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Patents Submitted

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Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Joseph Chavez	0.16	
Joyce Ahlgren	0.15	
FTE Equivalent:	**0.31**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

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This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
Gregory Chung	0.08
Ayesha Madni	0.12
Christopher Mullin	0.00
Larry Casey	0.00
FTE Equivalent:	**0.20**
Total Number:	**4**

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Inventions (DD882)

Scientific Progress

This portion is also in the attached MS Word file. The attachment contains the appendices, tables, and figures, which cannot be displayed here.

The focus of this project was to develop and test the effectiveness of gameplay on learning of solving equations concepts with students enrolled in a developmental math course at California State University, San Bernardino (CSUSB). The project combines the subject matter expertise of the math department at CSUSB, the game development and assessment expertise of CRESST, and the expertise on motivational issues (particularly with the Hispanic/Latino students at CSUSB) of the University of Southern California (USC).

Prior research on the solving equations suggests that simplifying expressions can be a mysterious process to students who have poor understanding of mathematics (Chung and Delacruz, 2014). The mathematical justifications for a transition from one step to the next, as depicted in textbooks and typical math instruction, often focuses only on the major transformative operations (e.g., distribution, identity properties) and often ignores the steps that may be tedious to illustrate and too obvious to include (e.g., regrouping, associative, commutative). Yet for students not fluid in the interpretation or use of the mathematical rules and properties, these intermediate steps as well as the more general technique of specifying the step-to-step transition may be a fruitful way to support the development of students' skill in simplifying expressions. The game developed in this grant implements a design that uses the step-to-step transitions as the core game mechanic, and exposes students to the "micro steps" often left out of textbook and classroom examples.

This project was accomplished over four phases. The first phase involved identifying the specific mathematical topics to be tested. Additionally this initial phase included identifying the target outcome performance, which was for students to be able to work through a problem and explain their problem solving process step by step. This phase took place from May 2012 through July 2012.

During the second phase, a prototype game developed and pilot tested with CSUSB students. Based on student responses, the prototype was updated to modify the type of feedback provided about specific errors. This modified version was also class tested during this phase. This phase took place from August 2012 through July 2013.

During the third phase, we focused on the major types of mathematical errors committed by students during game play and redesigning the game to provide more focused practice on those topics. This phase took place from August 2013 through July 2014.

During the final phase, the revised game was class tested. An analysis of the results was completed.

Phase I
Identify the math domain and outcome performance

During the summer of 2012 CSUSB identified the math domain, course, and particular topics within the course to target for gameplay. Math 90, Development Mathematics (intermediate algebra), was the course selected for this project. The major topics in Math 90 are: (a) Systems of Linear Equations and Inequalities; (b) Equations and Inequalities in One Variable; (c) Graphs, Relations, and Functions; (d) Introduction to Graphing and Equations of Lines; (e) Rational Expressions and Equations; (f) Radicals and Rational Exponents; and (g) Quadratic Equations and Functions.

Within these topics, the domain Radicals and Rational Exponents was selected. The sub-topics that will be tested are: nth roots and rational exponents and simplify expressions using laws of exponents. These sub-topics were selected because of their difficulty for a large number of students and their importance to subsequent mathematics. A poor understanding of the laws of exponents will not only result in a poor understanding of operations on exponents, but also impoverished understanding of advanced topics that require exponents such as quadratic equations and their applications.

Target performance: The target outcome performance is for students to be able to work through a problem and explain their problem solving process step-to-step.

Identify the common errors that students possess in that domain

CSUSB and CRESST have conducted several knowledge acquisition sessions that have focused on identifying the common student errors with respect to exponents. The purpose for focusing on common errors is that common errors provide a glimpse into (the lack of) student understanding—the prior knowledge students may lack that lead to such errors and the kind of thinking processes and aberrant beliefs students hold that may cause them to approach problem solving in a particular way.

Common errors also provide convenient “traps” that in a game context can result in engaging gameplay. This particular aspect of gameplay—making play challenging—can both expose students’ brittle understanding and provide instructional opportunities via instructional feedback and player-initiated help. The idea of impasse-driven learning and how to best structure instructional feedback in a game is a major long-term scientific goal of the project. Examples of the kinds of common errors fell into six categories and are shown in Appendix P1-A (See the attachment).

Identify candidate game mechanics to test that could be used for instructional and assessment purposes

A clear requirement for the game that flowed from the knowledge acquisition sessions is that students often simply memorize procedures and do not understand why a certain mathematical operation applies—“it simply does.” Thus, the CSUSB SME believed it was very important that the game help students make explicit their thinking process via interrogation techniques (e.g., posing questions to students and not simply telling students; having students explain what they are doing and not just require them to do something). These also happen to be techniques used in games to increase players’ interest and engagement in games.

The candidate game mechanics are:
1. Questioning techniques. For example, an avatar asks the student whether he or she thinks an operation might work or elicits from students the next step in the problem solving process.
2. Explanation techniques. For example, require the student to explain why he or she thinks a particular mathematical operation might work. Or require students to explain the critical difference between two contrasting cases.
3. Use of worked examples. For example, provide a worked example of how to solve an equation and slowly fade away the amount of support over a series of problems.

Develop measures

A set of measures have been identified for the research. The types of measures are: (a) prior knowledge of the content; (b) post-game knowledge of the content; (c) background information such as prior math grades, SAT/ACT scores, game experience, demographics information (age, sex, race, class standing, major); (d) English language proficiency; and (e) math self-efficacy and interest in math. Draft measures are shown in Appendix P1-B to Appendix P1-E (See the attachment).

The knowledge measures will target the specific content covered in the game in various formats (e.g., cast in terms of the game; cast symbolically as in a typical math test). Items susceptible to common errors also will be included in the item set, as well as items that require students to explain their problem solving step-by-step. The non-knowledge items will be adapted from prior studies.

Develop high-level game requirements

A preliminary set of broad requirements for the game was developed from the knowledge acquisition sessions. Specifically, the following strategies were identified as desirable for the Math 90 student population:

- Use interrogation strategies typical in games—questioning avatar (vs. telling avatar)
- Embed motivational components such as incremental success and self-reflection strategies
- Focus on diagnostics—detect what students know and common errors
- Report diagnostics back to instructor and students
- Focus on type of instructional feedback
- Questioning vs. telling—good game design
- Challenge level—ok for “weird” assessment levels
- Focus directly on symbolic manipulation

Phase 2
During this phase a prototype game was developed and pilot tested with CSUSB students. Based on student responses, the prototype was updated to modify the type of feedback provided about specific errors. This modified version was also class tested during this phase.

The prototype game consisted of 22 levels. See Appendix P2-A (See the attachment) for a screenshot of the prototype version of the game. Levels 1-12 required participants to select the immediate next step to the problem. Levels 13-22 required participants to solve multistep problems. Participants were shown a total points (one point for each correct step selected), bonus points (one point for each “mental step” step elected), and total completed problems (one point for each problem completed before time ran out).

Based on the pilot test performed in November 2012, it was apparent that students not only enjoyed playing the game, but also

felt that they learned from the game. In particular, students reported that they thought that receiving feedback immediately on each mathematical step was more effective than having to work through an entire math problem and not know which step in the process might have contributed to an incorrect solution.

However, student responses related to the next step process (as a form of instruction) and the type of feedback provided (e.g., receiving feedback about specific errors) seemed somewhat unclear. As such the prototype was updated to provide more explicit and targeted feedback options related to each mathematical step, and more sophisticated help options/menus for students to access when experiencing difficulty during gameplay. Screenshots depicting example feedback options and help menus are provided in Appendix P2-B (See the attachment).

Additional levels were also created to reflect more consistency across math item expressions and steps. In other words, representations of mathematical expressions or transformations were created to be consistent across items as well as consistent with how the students were taught to transform math items and depict math expressions. The following section provides further detail about the specific instructional variations within the game.

Develop instructional variations within the game

The following key instructional variation components were developed for testing purposes within the game:

Step-to-step transitions: the math problems were structured such that students were able to observe the steps required to solve the problem including incorrect steps and common errors, and select from those steps the next correct step in the problem sequence. See Appendix P2-C for an example (See the attachment).

Help menu with worked examples and explanations: these help features were available for students to access when needed during gameplay, and certain feedback prompts recommended students view specified help menus for further explanation. (See Appendix P2-B in the attachment)

Feedback variations

Implicit: this type of feedback allowed students to understand that the step they selected was either incorrect or correct by either sticking to or not sticking to the target problem or preceding step.

Knowledge of results: this type of feedback provided students with an image or statement indicating that their action was correct or incorrect (e.g., “Sorry, that was incorrect. Please try again.”), or that they received a bonus point.

Elaboration: this type of feedback provided students with an elaborated statement and suggestion about their miss step (e.g., “Oops! Looks like you separated the negative and you shouldn’t have. It should stay with the 125 under the root bar. Think about what number is the cube root of 125”). A variation of this feedback type also included an image of an example problem, or directing students to the help menu for further examples.

Determine overall game effectiveness and effectiveness of instructional variations

To determine overall game effectiveness and usability, and effectiveness of instructional variations, three tests were performed; November 2012, February 2013, and May 2013. The below sections detail the November 2012 and February 2013 studies. The data for the May 2013 study are being analyzed.

November 2012: The purpose of the November 2012 testing was to determine game usability, receive student feedback on the game-playing experience, and test the software data logging. Fifteen participants played the prototype game for 30-60 minutes. After playing the prototype game, participants were administered a survey. The survey consisted of 24 selected response questions and eight open-ended response questions.

Participants reported enjoying the experience of playing the prototype. Participants also reported that they learned from the game and that the game helped them with something they didn’t know before. They thought that this type of activity (getting feedback immediately on each step) was more effective than other similar activities such as homework. However, when asked specifically about the next step process and receiving feedback about errors, there was a wide range of responses They also thought that earning points, especially the bonus points, was motivating.

February 2013: The purpose of the February 2013 testing was to determine game effectiveness and effectiveness of measures, check for learning gains and condition differences (i.e., feedback variations), gather student perception data (i.e., math attitudes and game perceptions), and determine that student process data was being logged correctly during gameplay.

Participants were randomly assigned to both the control ($n = 57$) and treatment ($n = 54$) condition. Data analysis indicated that the conditions were similar across most background and demographic variables. However, the control group reported significantly higher ($p = .04$) interest in math than the treatment group, and marginally significant differences ($p = .06$) were found for GPA between groups with the treatment group scoring higher. No differences were found in pretest scores and self-belief in math. (See Appendix P2-D, Table 1 for details in the Attachment).

An ANOVA was conducted to determine if there was an interaction between assessment form and condition. No significant interaction was found on pretest or posttest, and no main effects for assessment form or condition were found on pretest or posttest. Results further indicated that were was no significant difference between conditions on the posttest.

Analysis of performance on math scores revealed that there was an approximately 11 % gain from pretest to posttest for both the control and treatment condition. (See Appendix P2-D, Table 2 for details) (See the attachment). Table 3 (see Appendix P2-D in the Attachment) reports item-level performance on the pretest and posttest. These findings indicated that approximately 12% of students scored incorrect on two pretest items then correct on the posttest, and 18% increased from incorrect to correct on and additional three other items on the posttest. The remaining two items showed increases between 28% and 40% of

students from pretest to posttest. Individual test items were also analyzed using the McNemar test to determine significant change from pretest to posttest. Results indicated a significant change from pretest to posttest for items 5, 10, and 11. (see Table 3, Appendix P2-D in the Attachment). In sum, the results indicated a small overall increase of scores from pretest to posttest, with higher performance gains appearing for specific items.

Based on the February 2013 testing, a few more levels were added to the game to target additional math problems, some images were changed to more clearly depict feedback and examples, and some items on the pre and post assessment were changed based on instructor feedback and student performance.

May 2013: The main purpose of the May 2013 testing was to evaluate an initial version of the game based on changes after the February results. Similar to February 2013 testing, the goal for May 2013 testing was also to determine game effectiveness and learning gains, check for differences across conditions (i.e., feedback, no feedback), and test software data logging and gather student perception data regarding math and gameplay.

Phase 3

The major scientific objectives of this phase were to determine the major types of mathematical errors committed by students during gameplay and to redesign the game levels to provide more focused practice on those topics.

Error Analysis

Prior to conducting the error analysis, the problems used in the game were subjected to a feature analysis. The feature analysis identified unique properties of the problems in terms of the structure of the problem (e.g., whether the problem has negative terms), cognitive demands (e.g., whether students were required to transform an expression from an exponent form to a radical form), and mathematical topic (e.g., application of the negative exponent rule). Table 1 (See the attachment) shows the set of features used to describe the problems used in the game.

Types of Errors

The problem steps associated with errors committed by at least 30 students were examined and represented 25 different errors. Thirty students represented 30% of the sample and the types of errors appeared to be representative of the remaining errors in the sample. The errors were committed over 12 game levels, with level 45 having the highest number of errors (7).

Errors were detected when students attempted to specify the next step given an existing step. In general, the next step represented the application (or misapplication) of an exponent rule and inspection of the errant next step provided insight into students' understanding as students attempted to simplify the expression. For example, on level 21, given the expression, 3^(1/3)·3^(1/3), 58 students specified 9^(1/9) as the next step and 57 students specified 3^(1/9) as the next step. In both cases, the misapplication of the power rule is clear and reflects a common error of multiplying exponents (instead of adding them). The second error also reflects an additional misconception of multiplying the base. The 25 errors committed by at least 30 or more students is given in Appendix P3-A (See the attachment)and frequency information on all errors committed by all students is given in Appendix P3-B (See the attachment).

To better understand the context of the errors, each error was examined in terms of the concept that was misapplied, the term property, and problem type (as defined by the feature analysis in Table 1 (See the attachment)). Many of the errors were related to the misapplication of the power rule, incorrect transformation between exponent and root forms, apparent confusion about the convention related to the negative sign and powers, and the misapplication of the negative exponent rule. These major errors served as the basis for redesigning the game levels and assessments.

Game Level Revisions

The revised game level design incorporates the results of the error analysis in the following ways. First, the problems in the new game levels focus exclusively on the following concepts: (a) exponent to root transformations; (b) negative exponent rule; and (c) power rule. Second, the problems incorporate negative numbers both as exponent properties as well as term properties. Finally, problems sets composed of 4 levels have been created to structure gameplay to emphasize practice and reflection. As in the original game, the game levels are divided into 2 stages. Stage 1 is designed to provide students with practice on basic concepts and Stage 2 is designed to provide students with applying the concepts. Additionally, two types of problem types have been added: a self-explanation question that asks students to explain their choice, and a challenge problem that gives students only a single chance to transform the problem. The challenge problem serves as an in-game measure of learning for a particular problem set.

Stage 1: Single step transformations. Transformations cover basic concepts using single-term, single-step problems. There are six problem sets (PS) in Stage 1. PS 1 requires students to transform from exponential form to root form, PS 2 requires students to transform negative exponents into positive exponents, and PS 3 combines these two concepts. PS 4 provides practice with negative signs. PS 5 increases complexity of expressions by including negative terms and positive and negative fractional exponents. PS 6 introduces students to the power rule, required for multi-term problems in Stage 2.

Each PS includes four problems: (a) a single-step problem with feedback; (b) a single-step problem requiring students to explain their reasoning behind their answer; (c) another single-step problem with feedback to gauge any change in their reasoning based on their self-explanation; and (d) a challenge problem with no feedback. Table 2 (See the attachment) shows the Stage 1 problem set sequence.

Stage 2: Multistep transformations. Stage 2 problem sets require multistep solutions. PS 7 includes four problems: Problems a to c are multi-step problems with feedback and problem d is a challenge problem. No self-explanation problems are included. The remaining problem sets require some use of the power rule to distribute an exponent to multiple terms. The steps also

require students to apply the rules learned in the Stage 1 problem sets. PS 8 to 11 include three problems: Problems a and b are multi-step problems with feedback and problem c is a challenge problem. No self-explanation problems are included. Table 3 (See the attachment) shows the Stage 2 problem set sequence.

Phase 4

Game goal and mechanics. The goal of the game is for players to simplify a given expression by specifying the next step in the simplification process. To start the process, a single tile with a picture of the to-be-simplified expression is placed on the main game board. Time pressure, a common game design element, is incorporated by having the tile slowly creep to the top of the game board. The player must select the “next step” from a set of available tiles on left side of the game board and drop it on the target tile as shown in Figure 1 (See the attachment). If the dropped tile is a correct next step, the dropped tile is attached to the bottom of the target tile. In Figure 1, the initial tile is the expression (-125)^(1/3) and a valid next step has been dropped on the initial tile. The stack is slowly moving to the top of the board.

To help students to focus on the micro steps between the transitions between major steps, the game awards bonus points when students use a micro step, with a “bonus” splash screen appearing momentarily to indicate a bonus (or use of a micro step).

Instructional design. The game focuses on the following concepts: (a) exponent to root transformations; (b) negative exponent rule; and (c) power rule. Many of the problems incorporate negative numbers both as exponent properties as well as term properties. Problem sets composed of 4 levels each structure gameplay to emphasize practice and reflection. The game levels are divided into 2 stages. Stage 1 is designed to provide students with practice on basic concepts and Stage 2 is designed to provide students with applying the concepts. Additionally, challenge problems exists that gives students only a single chance to transform a problem. The challenge problem also serves as an in-game measure of learning.

Stage 1 design. There were 24 levels in Stage 1. The levels cover basic concepts using single-term, single-step problems. There are six problem sets (PS) in Stage 1. PS 1 requires students to transform from exponential form to root form, PS 2 requires students to transform negative exponents into positive exponents, and PS 3 combines these two concepts. PS 4 provides practice with negative signs. PS 5 increases complexity of expressions by including negative terms and positive and negative fractional exponents. PS 6 introduces students to the power rule, required for multi-term problems in Stage 2.

Each problem set includes four problems: (a) a single-step problem with feedback; (b) a single-step problem requiring students to explain their reasoning behind their answer; (c) another single-step problem with feedback to gauge any change in their reasoning based on their self-explanation; and (d) a challenge problem with no feedback. Table 4 (See the attachment) shows Stage 2 design. There are 16 levels in Stage 2. The levels in Stage 2 problem sets require multistep solutions. PS 7 includes four problems: Problems a to c are multi-step problems with feedback. No self-explanation problems are included in Stage 2. The remaining problem sets require some use of the power rule to distribute an exponent to multiple terms. The steps also require students to apply the rules learned in the Stage 1 problem sets. PS 8 to 11 include three problems: Problems a and b are multi-step problems with feedback and problem c is a challenge problem. No self-explanation problems are included. Table 3 (See the attachment) shows the Stage 2 problem set sequence.

Research Questions

The main research questions for this study are: To what extent does self-explanation of exponent rules in a game affect their application of exponent rules and perceptions of engagement? To what extent does can game-based practice of exponent rules improve students’ application of those exponent rules?

Method

Participants and Design

Participants. The sample comprised 69 participants (19 males, 47 females, 3 unreported) who were ethnically diverse (42 Latino/a, 9 White, 8 Black or African American, 2 Asian or Pacific Islander, 3 Multiracial/multiethnic, and 5 unspecified) and with a mean age of 19.2 years old (SD = 3.8 years). When asked how frequently a language other than English is spoken at home, 20 students (29%) reported all or most of the time, 23 (33%) about half of the time, 12 (17%) once in a while, and 11 (16%) never. Eighteen students reported they were repeating the class, 28 students took the preceding course, and 20 students reported this was their first college math course. The mean overall GPA reported by students was 3.16 (SD = 0.47) on a 4.0 scale. When asked about their gameplay skill, 16 students (23%) reported they were very good, 13 (19%) reported good, 24 (35%) reported their skill as fair, and 13 (19%) reported poor gameplay skills. When asked how many hours per week they spend playing games, 26 participants (38%) reported 0 hours, 29 participants (42%) reported 1-4 hours, 7 participants reported 5-8 hours, and 1 participant report 13 or more hours. Finally, the mean score (on a 1 to 4 point scale) for participants’ interest in math and math self-efficacy were M = 2.48 (SD = 0.71) and M = 2.5 (SD = 0.75). Overall, the sample appeared to be of average achievement, ethnically diverse, and have a moderate degree of game experience. Participants’ interest and self-efficacy were at the scale midpoints and normally distributed, suggesting the sample was not overly interested or disinterested in math, nor excessively possess high or low in math self-efficacy.

Design. A two-group, pretest-posttest experimental design was used. Participants were randomly assigned to either a baseline game condition or a self-explanation condition.

Measures

Prerequisite knowledge. Four questions were asked to gather information on participants’ proficiency with basic fraction addition, multiplication, and order of operations.

Rules of exponent. Three scales were developed to measure three skills: (a) converting an exponent to its root form (ETR), (b)

application of the negative exponent rule (NER), and (c) application of the power rule (PR). A fourth scale was developed to examine transfer performance (XFER) and included topics from each of the other scales but the problems were more complex in terms of the number of variables in the expressoin. The ETR scale had 8 items (pretest $\alpha = .73$; posttest $\alpha = .74$), NER scale 6 items (pretest $\alpha = .60$; posttest $\alpha = .73$), the PR scale had 4 items (pretest $\alpha = .82$; posttest $\alpha = .65$), and the XFER scale had 5 items (posttest-only $\alpha = .71$).

Game perception. Two scales were used to measure participants' perception of their game experience. The engagement scale (I really got into the game, Doing the game was boring, I would have liked to play longer, I thought the game was a waste of time, Beating the different levels made me feel good) and a perceived learning scale (I learned something new about exponents/roots/math from the game, The game helped me figure out something I previously had trouble with, I realized I had a misconception about an exponent/root topic while playing the game). The 5-item perceived engagement scale $\alpha = .75$ and 3-item perceived learning scale $\alpha = .85$.

Feedback about the game. Participants were asked to provide feedback about their experience with the game. Participants were asked three questions (How do you think this game compares to other ways of practicing math (e.g., doing problems on paper)?; How helpful (for learning) do you think it was to emphasize the "next step" in the problem solving process? Overall, how much did you learn about exponents/roots from the game?). Each question had Likert-type anchors as well as space for written comments.

Background. Participants were asked to complete a questionnaire asking for their age, gender, ethnicity, and frequency of speaking a language other than English at home. In addition, participants self-reported their overall GPA, transfer status, skill with video games, and number of hours per week spent playing games. Participants were also asked about their interest in math and math self-efficacy. These scales were adopted from Marsh, Hau, Artlet, Baumert, and Peschar (2006). The interest in math scale had 3 items ($\alpha = .72$) and math self-efficacy scale 3 items ($\alpha = .80$).

Game

Base version. The base version was the game as described earlier. There were 24 levels requiring single-step transformations (Stage 1) and 16 levels require multiple-step transformations (Stage 2). Students were not required to self-explain their selections.

Experimental version. The experimental version of the game required participants to engage in self-explanation during selected levels in Stage 1. There were 6 levels that required self-explanation. There were 4 levels in a problem set. The design of the levels within a problem set was to first provide a level that provided minimal feedback to participants if they selected an incorrect step. Then a level with a similar problem was presented except with a self-explanation prompt appearing immediately after the student dropped the next step tile onto target tile on the game board. No feedback was given to students about the accuracy of their self-explanation. The self-explanation prompt was a list of exponent rules. Participants were instructed to choose the rule that justified their next step as shown in Figure 2 (See the attachment).

Procedure

Participants were introduced to the study and then provided all materials (pretest, laptop computer, and posttest). Participants were instructed to start on the pretest. After completing the pretest, the pretest was collected and participants were instructed to start the game on the laptop. After completing the game at their own pace, participants started the posttest and completed the test at their own pace. All participants except 2 finished all materials. These two participants did not finish the game nor the posttest.

Results

Preliminary Analyses

A check for differences between conditions was conducted for the pretest and background measures. An independent t-test was conducted on the prerequisite knowledge items, the three rules of exponent scales, the two attitudinal scales, and the two game experience questions. There were no differences between conditions on any measure ($p > .05$) suggesting that the randomization procedure worked.

Descriptive Statistics

(See the attachment)

Main Analyses

Performance. Separate repeated-measures ANOVAs were conducted on the ETR, NER, and PR scales. To simultaneously determine if there was a condition effect as well as a learning effect, participants performance were analyzed with a 2(condition) $\subseteq$ 2(occasion) ANOVA, with occasion as the within-subjects factors, and condition as the between-subjects factor. No significant condition $\subseteq$ occasion interaction was found for ETR, NER, or PR scales, suggesting that there were no effects of self-explanation on participants' learning of those topics. For the transfer task, an independent t-test was conducted on the XFER scale to test for differences between conditions. No differences were found.

However, a significant within-subjects main effect of occasion was found for ETR ($F[1, 65] = 12.82$, $MSE = 1.12$, $p = .001$), NER ($F[1, 65] = 19.42$, $MSE = 17.16$, $p < .001$), and PR ($F[1, 65] = 12.82$, $MSE = 14.13$, $p = .001$), suggesting that participants learned over the course of the game. Table 7 displays the descriptive statistics, effect size of the change (Dunlap, Cortina, Vaslow, & Burke, 1996), and percent increase for each scale. The largest increase was found for the exponent to root transformation problems.

Perceived learning and engagement. To examine the effects of self-explanation on participants' perceived engagement, an independent t-test was conducted to test the effects of condition on perceived learning and participants' perceived engagement.

No differences were found for participants' perceived learning. However, participants who received the self-explanation prompts (M = 3.07 SD = 0.56), compared to participants who did not receive self-explanation prompts (M = 2.68, SD = 0.58), had significantly lower ratings of their experience, $t(63) = 2.73$, $p = .008$, $d = 0.68$. The large effect size suggests that the self-explanation prompts interfered with participants' perceived engagement with the game.

Usability. The last analysis examined participants' perceptions of their experience. Table 8 shows the frequency of responses to three questions: (a) How do you think this game compares to other ways of practicing math (e.g., doing problems on paper)? (b) How helpful (for learning) do you think it was to emphasize the "next step" in the problem solving process? and (c) Overall, how much did you learn about exponents/roots from the game?

Overall, participants reported very favorable responses to the game, with 59% of the same reporting the game was more or much more effective than other ways of practicing math. This is remarkable considering the game was in a pre-prototype stage, did not mask the mathematics, and provided minimal game garnishes. Thirty-three percent of students reported the emphasis of the next step as being very or extremely helpful for learning, with an additional 39% reporting the emphasis on "next steps" as helpful. Finally, 27% of students reported the game as helping them learn a lot about exponents/roots and 67% reporting the game help them some.

Conclusion

Overall, the pre-prototype game appeared to provide students with an engaging and beneficial experience. With less than 40 minutes of gameplay time, students improved their performance on math problems related to converting an exponent to its root form, applying the negative exponent rule, and applying the power rule, and reported high levels of utility. This is an interesting finding because it suggests that the instructional sequence, game mechanics, and focus on problems susceptible to common errors collectively helped students improve their performance substantially, as indicated by the moderate to large pretest-to-posttest effects sizes ranging from .40 to .73.

The lack of finding an effect of the self-explanation prompts is curious. We followed the similar procedures used by Mayer and Johnson (2010) and Johnson and Mayer (2013), who found that the when people are asked to select self-explanations for their moves in a game, they learn more (compared to people who are not asked to select an explanation). Our results are more in line with O'Neil et al. (2014), who found no main effect of self-explanation in math learning in a game. O'Neil et al. concluded that the most effective self-explanations where those that prompted connections between the concrete elements in the game and the abstract mathematics terminology. The least effective self-explanation prompts were those that asked very simple or very abstract questions. It may be the case for our game and participants, the self-explanation prompts may been too abstract as the choices were the symbolic representation of the exponent rule. Further research is needed to explore this issue.

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Technology Transfer

Using Game Play to Diagnose and Remediate Students' Misconceptions in Solving Equations

Contract Number W911NF-12-1-0077

Final Report

The focus of this project was to develop and test the effectiveness of gameplay on learning of solving equations concepts with students enrolled in a developmental math course at California State University, San Bernardino (CSUSB). The project combines the subject matter expertise of the math department at CSUSB, the game development and assessment expertise of CRESST, and the expertise on motivational issues (particularly with the Hispanic/Latino students at CSUSB) of the University of Southern California (USC).

Prior research on the solving equations suggests that simplifying expressions can be a mysterious process to students who have poor understanding of mathematics (Chung and Delacruz, 2014). The mathematical justifications for a transition from one step to the next, as depicted in textbooks and typical math instruction, often focuses only on the major transformative operations (e.g., distribution, identity properties) and often ignores the steps that may be tedious to illustrate and too obvious to include (e.g., regrouping, associative, commutative). Yet for students not fluid in the interpretation or use of the mathematical rules and properties, these intermediate steps as well as the more general technique of specifying the step-to-step transition may be a fruitful way to support the development of students' skill in simplifying expressions. The game developed in this grant implements a design that uses the step-to-step transitions as the core game mechanic, and exposes students to the "micro steps" often left out of textbook and classroom examples.

This project was accomplished over four phases. The first phase involved identifying the specific mathematical topics to be tested. Additionally this initial phase included identifying the target outcome performance, which was for students to be able to work through a problem and explain their problem solving process step by step. This phase took place from May 2012 through July 2012.

During the second phase, a prototype game developed and pilot tested with CSUSB students. Based on student responses, the prototype was updated to modify the type of feedback provided about specific errors. This modified version was also class tested during this phase. This phase took place from August 2012 through July 2013.

During the third phase, we focused on the major types of mathematical errors committed by students during game play and redesigning the game to provide more focused practice on those topics. This phase took place from August 2013 through July 2014.

During the final phase, the revised game was class tested. An analysis of the results was completed.

Phase I

Identify the math domain and outcome performance

During the summer of 2012 CSUSB identified the math domain, course, and particular topics within the course to target for gameplay. Math 90, Development Mathematics (intermediate algebra), was the course selected for this project. The major topics in Math 90 are: (a) Systems of Linear Equations and Inequalities; (b) Equations and Inequalities in One Variable; (c) Graphs, Relations, and Functions; (d) Introduction to Graphing and Equations of Lines; (e) Rational Expressions and Equations; (f) Radicals and Rational Exponents; and (g) Quadratic Equations and Functions.

Within these topics, the domain *Radicals and Rational Exponents* was selected. The sub-topics that will be tested are: *nth roots and rational exponents* and *simplify expressions using laws of exponents*. These sub-topics were selected because of their difficulty for a large number of students and their importance to subsequent mathematics. A poor understanding of the laws of exponents will not only result in a poor understanding of operations on exponents, but also impoverished understanding of advanced topics that require exponents such as quadratic equations and their applications.

Target performance: The target outcome performance is for students to be able to work through a problem and explain their problem solving process step-to-step.

Identify the common errors that students possess in that domain

CSUSB and CRESST have conducted several knowledge acquisition sessions that have focused on identifying the common student errors with respect to exponents. The purpose for focusing on common errors is that common errors provide a glimpse into (the lack of) student understanding—the prior knowledge students may lack that lead to such errors and the kind of

thinking processes and aberrant beliefs students hold that may cause them to approach problem solving in a particular way.

Common errors also provide convenient “traps” that in a game context can result in engaging gameplay. This particular aspect of gameplay—making play challenging—can both expose students’ brittle understanding and provide instructional opportunities via instructional feedback and player-initiated help. The idea of impasse-driven learning and how to best structure instructional feedback in a game is a major long-term scientific goal of the project. Examples of the kinds of common errors fell into six categories and are shown in Appendix P1-A.

Identify candidate game mechanics to test that could be used for instructional and assessment purposes

A clear requirement for the game that flowed from the knowledge acquisition sessions is that students often simply memorize procedures and do not understand why a certain mathematical operation applies—“it simply does.” Thus, the CSUSB SME believed it was very important that the game help students make explicit their thinking process via interrogation techniques (e.g., posing questions to students and not simply telling students; having students explain what they are doing and not just require them to do something). These also happen to be techniques used in games to increase players’ interest and engagement in games.

The candidate game mechanics are:

1. Questioning techniques. For example, an avatar asks the student whether he or she thinks an operation might work or elicits from students the next step in the problem solving process.

2. Explanation techniques. For example, require the student to explain why he or she thinks a particular mathematical operation might work. Or require students to explain the critical difference between two contrasting cases.

3. Use of worked examples. For example, provide a worked example of how to solve an equation and slowly fade away the amount of support over a series of problems.

Develop measures

A set of measures have been identified for the research. The types of measures are: (a) prior knowledge of the content; (b) post-game knowledge of the content; (c) background information such as prior math grades, SAT/ACT scores, game experience, demographics information (age, sex, race, class standing, major); (d) English language proficiency; and (e) math self-efficacy and interest in math. Draft measures are shown in Appendix P1-B to Appendix .

The knowledge measures will target the specific content covered in the game in various formats (e.g., cast in terms of the game; cast symbolically as in a typical math test). Items susceptible to common errors also will be included in the item set, as well as items that require students to explain their problem solving step-by-step. The non-knowledge items will be adapted from prior studies.

Develop high-level game requirements

A preliminary set of broad requirements for the game was developed from the knowledge acquisition sessions. Specifically, the following strategies were identified as desirable for the Math 90 student population:

- Use interrogation strategies typical in games—questioning avatar (vs. telling avatar)
- Embed motivational components such as incremental success and self-reflection strategies
- Focus on diagnostics—detect what students know and common errors
- Report diagnostics back to instructor and students
- Focus on type of instructional feedback
- Questioning vs. telling—good game design
- Challenge level—ok for “weird” assessment levels
- Focus directly on symbolic manipulation

Phase 2

During this phase a prototype game was developed and pilot tested with CSUSB students. Based on student responses, the prototype was updated to modify the type of feedback provided about specific errors. This modified version was also class tested during this phase.

The prototype game consisted of 22 levels. See Appendix P2-A for a screenshot of the prototype version of the game. Levels 1-12 required participants to select the immediate next

step to the problem. Levels 13-22 required participants to solve multistep problems. Participants were shown a total points (one point for each correct step selected), bonus points (one point for each “mental step” step elected), and total completed problems (one point for each problem completed before time ran out).

Based on the pilot test performed in November 2012, it was apparent that students not only enjoyed playing the game, but also felt that they learned from the game. In particular, students reported that they thought that receiving feedback immediately on each mathematical step was more effective than having to work through an entire math problem and not know which step in the process might have contributed to an incorrect solution.

However, student responses related to the next step process (as a form of instruction) and the type of feedback provided (e.g., receiving feedback about specific errors) seemed somewhat unclear. As such the prototype was updated to provide more explicit and targeted feedback options related to each mathematical step, and more sophisticated help options/menus for students to access when experiencing difficulty during gameplay. Screenshots depicting example feedback options and help menus are provided in Appendix P2-B.

Additional levels were also created to reflect more consistency across math item expressions and steps. In other words, representations of mathematical expressions or transformations were created to be consistent across items as well as consistent with how the students were taught to transform math items and depict math expressions. The following section provides further detail about the specific instructional variations within the game.

Develop instructional variations within the game

The following key instructional variation components were developed for testing purposes within the game:

- Step-to-step transitions: the math problems were structured such that students were able to observe the steps required to solve the problem including incorrect steps and common errors, and select from those steps the next correct step in the problem sequence. See Appendix P2-C for an example.
- Help menu with worked examples and explanations: these help features were available for students to access when needed during gameplay, and certain feedback prompts recommended students view specified help menus for further explanation. (See Appendix P2-B)
- Feedback variations
    - Implicit: this type of feedback allowed students to understand that the step they selected was either incorrect or correct by either sticking to or not sticking to the target problem or preceding step.
    - Knowledge of results: this type of feedback provided students with an image or statement indicating that their action was correct or incorrect (e.g., “Sorry, that was incorrect. Please try again.”), or that they received a bonus point.

- Elaboration: this type of feedback provided students with an elaborated statement and suggestion about their miss step (e.g., "Oops! Looks like you separated the negative and you shouldn't have. It should stay with the 125 under the root bar. Think about what number is the cube root of 125"). A variation of this feedback type also included an image of an example problem, or directing students to the help menu for further examples.

Determine overall game effectiveness and effectiveness of instructional variations

To determine overall game effectiveness and usability, and effectiveness of instructional variations, three tests were performed; November 2012, February 2013, and May 2013. The below sections detail the November 2012 and February 2013 studies. The data for the May 2013 study are being analyzed.

<u>November 2012</u>: The purpose of the November 2012 testing was to determine game usability, receive student feedback on the game-playing experience, and test the software data logging. Fifteen participants played the prototype game for 30-60 minutes. After playing the prototype game, participants were administered a survey. The survey consisted of 24 selected response questions and eight open-ended response questions.

Participants reported enjoying the experience of playing the prototype. Participants also reported that they learned from the game and that the game helped them with something they didn't know before. They thought that this type of activity (getting feedback immediately on each step) was more effective than other similar activities such as homework. However, when asked specifically about the next step process and receiving feedback about errors, there was a wide range of responses They also thought that earning points, especially the bonus points, was motivating.

<u>February 2013</u>: The purpose of the February 2013 testing was to determine game effectiveness and effectiveness of measures, check for learning gains and condition differences (i.e., feedback variations), gather student perception data (i.e., math attitudes and game perceptions), and determine that student process data was being logged correctly during gameplay.

Participants were randomly assigned to both the control (n= 57) and treatment (n= 54) condition. Data analysis indicated that the conditions were similar across most background and demographic variables. However, the control group reported significantly higher (p = .04) interest in math than the treatment group, and marginally significant differences (p = .06) were found for GPA between groups with the treatment group scoring higher. No differences were found in pretest scores and self-belief in math. (See Appendix P2-D, Table 1 for details).

An ANOVA was conducted to determine if there was an interaction between assessment form and condition. No significant interaction was found on pretest or posttest, and no main effects for assessment form or condition were found on pretest or posttest. Results further indicated that were was no significant difference between conditions on the posttest.

Analysis of performance on math scores revealed that there was an approximately 11 % gain from pretest to posttest for both the control and treatment condition. (See Appendix P2-D, Table 2 for details). Table 3 (see Appendix P2-D) reports item-level performance on the pretest and posttest. These findings indicated that approximately 12% of students scored incorrect on two pretest items then correct on the posttest, and 18% increased from incorrect to correct on and additional three other items on the posttest. The remaining two items showed increases between 28% and 40% of students from pretest to posttest. Individual test items were also analyzed using the McNemar test to determine significant change from pretest to posttest. Results indicated a significant change from pretest to posttest for items 5, 10, and 11. (see Table 3, Appendix P2-D). In sum, the results indicated a small overall increase of scores from pretest to posttest, with higher performance gains appearing for specific items.

Based on the February 2013 testing, a few more levels were added to the game to target additional math problems, some images were changed to more clearly depict feedback and examples, and some items on the pre and post assessment were changed based on instructor feedback and student performance.

May 2013: The main purpose of the May 2013 testing was to evaluate an initial version of the game based on changes after the February results. Similar to February 2013 testing, the goal for May 2013 testing was also to determine game effectiveness and learning gains, check for differences across conditions (i.e., feedback, no feedback), and test software data logging and gather student perception data regarding math and gameplay.

Phase 3

The major scientific objectives of this phase were to determine the major types of mathematical errors committed by students during gameplay and to redesign the game levels to provide more focused practice on those topics.

Error Analysis

Prior to conducting the error analysis, the problems used in the game were subjected to a feature analysis. The feature analysis identified unique properties of the problems in terms of the structure of the problem (e.g., whether the problem has negative terms), cognitive demands (e.g., whether students were required to transform an expression from an exponent form to a radical

form), and mathematical topic (e.g., application of the negative exponent rule). Table 1 shows the set of features used to describe the problems used in the game.

Table 1.
Features of Problem Steps in Game (5/21/2013 game version).

Category	Definition
Problem type	
Exponent to exponent	A term is transformed from an exponential term to an exponential term
Exponent to root	A term is transformed from an exponential term to a radical term
Root to exponent	A term is transformed from a radical term to an exponential term
Root to root	A term is transformed from a radical term to a radical term
Term properties	
Number of terms	The number of distinct terms in the problem (e.g., $8x^{\frac{1}{2}}$ has two terms, 8 and $x^{\frac{1}{2}}$)
Term type	
Letter or variable	Terms represented by letters (e.g., *a*, *b*, *x*, *y*)
Number or digit	Terms represented by numbers (e.g., 1, 2, 3)
Negative terms	
Inside parentheses or root	A negative term has a negative inside the parentheses or root (e.g., $(-8)^2$)
Outside parentheses or root	A negative term has a negative outside the parentheses or root (e.g., $-(8)^2$)
Term operations	
Addition or subtraction	Two or more terms are added or subtracted in the solution
Multiplication or division	Two or more terms are multiplied or divided in the solution
Fraction properties	
Number of fraction terms	The number of distinct fractional terms in the problem (e.g., $2^{\frac{1}{3}}x$ has one fractional term, $2^{\frac{1}{3}}$)
Exponent term type	
Fraction on letter or variable	Fractional terms appear on letter type terms (e.g.,$x^{\frac{3}{2}}, y^{\frac{5}{3}}$)
Fraction on number or digit	Fractional terms appear on number type terms (e.g.,$2^{\frac{1}{2}}, 4^{\frac{5}{6}}$)
Negative fraction	Negative fractional terms in the problem (e.g., $x^{-\frac{1}{2}}$)

Category	Definition	
Non-trivial		
Non-1 numerator	A numerator that is not 1; if 1, the term is raised to the 1st power (e.g., $a^{\frac{1}{2}}$ has a trivial numerator)	
Non-1 denominator	A denominator that is not 1; if 1, the exponential term is an integer (e.g., $a^{\frac{2}{1}}$ has a trivial denominator)	
Concept		
Zero exponent rule	$a^0 = 1$	if a ≠ 0
Negative exponent rule	$a^{-\frac{m}{n}} = \frac{1}{a^{\frac{m}{n}}}$ and $\frac{1}{a^{-\frac{m}{n}}} = a^{\frac{m}{n}}$	if a ≠ 0
Product rule	$a^r \cdot a^s = a^{r+s}$	
Quotient rule	$\frac{a^r}{a^s} = a^{r-s} = \frac{1}{a^{s-r}}$	if a ≠ 0
Power rule	$(a^r)^s = a^{r \cdot s}$	

Note. Names and definitions taken from Math 90 textbook.

Types of Errors

The problem steps associated with errors committed by at least 30 students were examined and represented 25 different errors. Thirty students represented 30% of the sample and the types of errors appeared to be representative of the remaining errors in the sample. The errors were committed over 12 game levels, with level 45 having the highest number of errors (7).

Errors were detected when students attempted to specify the next step given an existing step. In general, the next step represented the application (or misapplication) of an exponent rule and inspection of the errant next step provided insight into students' understanding as students attempted to simplify the expression. For example, on level 21, given the expression, $3^{\frac{1}{3}} \cdot 3^{\frac{1}{3}}$, 58 students specified $9^{\frac{1}{9}}$ as the next step and 57 students specified $3^{\frac{1}{9}}$ as the next step. In both cases, the misapplication of the power rule is clear and reflects a common error of multiplying exponents (instead of adding them). The second error also reflects an additional misconception of multiplying the base. The 25 errors committed by at least 30 or more students is given in Appendix P3-A and frequency information on all errors committed by all students is given in Appendix P3-B.

To better understand the context of the errors, each error was examined in terms of the concept that was misapplied, the term property, and problem type (as defined by the feature analysis in Table 1). Many of the errors were related to the misapplication of the power rule, incorrect transformation between exponent and root forms, apparent confusion about the convention related to the negative sign and powers, and the misapplication of the negative

exponent rule. These major errors served as the basis for redesigning the game levels and assessments.

Game Level Revisions

The revised game level design incorporates the results of the error analysis in the following ways. First, the problems in the new game levels focus exclusively on the following concepts: (a) exponent to root transformations; (b) negative exponent rule; and (c) power rule. Second, the problems incorporate negative numbers both as exponent properties as well as term properties. Finally, problems sets composed of 4 levels have been created to structure gameplay to emphasize practice and reflection. As in the original game, the game levels are divided into 2 stages. Stage 1 is designed to provide students with practice on basic concepts and Stage 2 is designed to provide students with applying the concepts. Additionally, two types of problem types have been added: a self-explanation question that asks students to explain their choice, and a challenge problem that gives students only a single chance to transform the problem. The challenge problem serves as an in-game measure of learning for a particular problem set.

Stage 1: Single step transformations. Transformations cover basic concepts using single-term, single-step problems. There are six problem sets (PS) in Stage 1. PS 1 requires students to transform from exponential form to root form, PS 2 requires students to transform negative exponents into positive exponents, and PS 3 combines these two concepts. PS 4 provides practice with negative signs. PS 5 increases complexity of expressions by including negative terms and positive and negative fractional exponents. PS 6 introduces students to the power rule, required for multi-term problems in Stage 2.

Each PS includes four problems: (a) a single-step problem with feedback; (b) a single-step problem requiring students to explain their reasoning behind their answer; (c) another single-step problem with feedback to gauge any change in their reasoning based on their self-explanation; and (d) a challenge problem with no feedback. Table 2 shows the Stage 1 problem set sequence.

Table 2.
Stage 1 Transformations Problem Set Sequence.

Problem set	Term property	Exponent property	Concepts
1a-d	Positive	Positive fractions	Exponent to root
2a-d	Positive	Negative integers	Negative exponent rule
3a-d	Positive	Negative fractions	Negative exponent rule, exponent to root
4a-d	Negative	Positive integers	Negative sign
5a-d	Negative	Positive and negative fractions	Exponent to root, negative exponent rule
6a-d	Positive	Positive integers and fractions	Power rule

Stage 2: Multistep transformations. Stage 2 problem sets require multistep solutions. PS 7 includes four problems: Problems *a* to *c* are multi-step problems with feedback and problem *d* is a challenge problem. No self-explanation problems are included. The remaining problem sets require some use of the power rule to distribute an exponent to multiple terms. The steps also require students to apply the rules learned in the Stage 1 problem sets. PS 8 to 11 include three problems: Problems *a* and *b* are multi-step problems with feedback and problem *c* is a challenge problem. No self-explanation problems are included. Table 3 shows the Stage 2 problem set sequence.

Table 3.
Stage 2 Multistep Transformations Problem Set Sequence.

Problem set	Term property	Exponent property	Concepts
7a-d	Positive	Positive and negative fractions	Exponents to roots, negative exponent rule
8a-c	Positive	Positive	Power rule
9a-c	Positive	Negative	Power rule, negative exponent rule
10a-c	Negative	Positive	Power rule, negative sign
11a-c	Positive	Negative	Power rule, negative exponent rule

Phase 4

Game goal and mechanics. The goal of the game is for players to simplify a given expression by specifying the next step in the simplification process. To start the process, a single tile with a picture of the to-be-simplified expression is placed on the main game board. Time

pressure, a common game design element, is incorporated by having the tile slowly creep to the top of the game board. The player must select the “next step” from a set of available tiles on left side of the game board and drop it on the target tile as shown in Figure 1. If the dropped tile is a correct next step, the dropped tile is attached to the bottom of the target tile. In Figure 1, the initial tile is the expression $(-125)^{\frac{1}{3}}$ and a valid next step has been dropped on the initial tile. The stack is slowly moving to the top of the board.

To help students to focus on the micro steps between the transitions between major steps, the game awards bonus points when students use a micro step, with a “bonus” splash screen appearing momentarily to indicate a bonus (or use of a micro step).

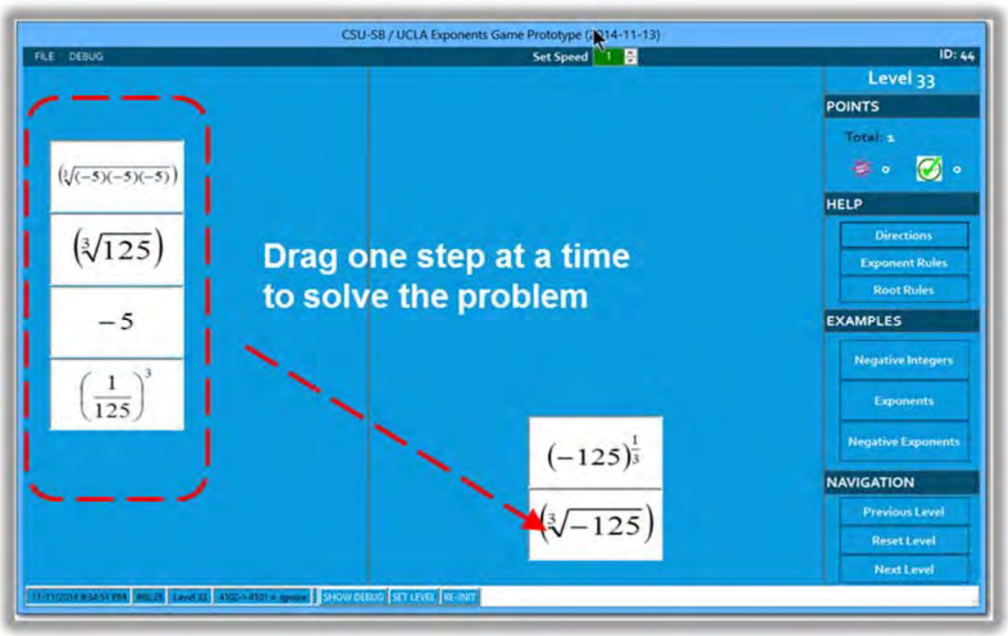

Figure 1. User interface of exponent game

Instructional design. The game focuses on the following concepts: (a) exponent to root transformations; (b) negative exponent rule; and (c) power rule. Many of the problems incorporate negative numbers both as exponent properties as well as term properties. Problem sets composed of 4 levels each structure gameplay to emphasize practice and reflection. The game levels are divided into 2 stages. Stage 1 is designed to provide students with practice on basic concepts and Stage 2 is designed to provide students with applying the concepts. Additionally, challenge problems exists that gives students only a single chance to transform a problem. The challenge problem also serves as an in-game measure of learning.

Stage 1 design. There were 24 levels in Stage 1. The levels cover basic concepts using single-term, single-step problems. There are six problem sets (PS) in Stage 1. PS 1 requires students to

transform from exponential form to root form, PS 2 requires students to transform negative exponents into positive exponents, and PS 3 combines these two concepts. PS 4 provides practice with negative signs. PS 5 increases complexity of expressions by including negative terms and positive and negative fractional exponents. PS 6 introduces students to the power rule, required for multi-term problems in Stage 2.

Each problem set includes four problems: (a) a single-step problem with feedback; (b) a single-step problem requiring students to explain their reasoning behind their answer; (c) another single-step problem with feedback to gauge any change in their reasoning based on their self-explanation; and (d) a challenge problem with no feedback. Table 4 shows the Stage 1 problem set sequence.

Table 4.

Stage 1 Transformations Problem Set Sequence.

Problem set	Term property	Exponent property	Concepts
1a-d	Positive	Positive fractions	Exponent to root
2a-d	Positive	Negative integers	Negative exponent rule
3a-d	Positive	Negative fractions	Negative exponent rule, exponent to root
4a-d	Negative	Positive integers	Negative sign
5a-d	Negative	Positive and negative fractions	Exponent to root, negative exponent rule
6a-d	Positive	Positive integers and fractions	Power rule

<u>Stage 2 design</u>. There are 16 levels in Stage 2. The levels in Stage 2 problem sets require multistep solutions. PS 7 includes four problems: Problems *a* to *c* are multi-step problems with feedback. No self-explanation problems are included in Stage 2. The remaining problem sets require some use of the power rule to distribute an exponent to multiple terms. The steps also require students to apply the rules learned in the Stage 1 problem sets. PS 8 to 11 include three problems: Problems *a* and *b* are multi-step problems with feedback and problem *c* is a challenge problem. No self-explanation problems are included. Table 3 shows the Stage 2 problem set sequence.

Table 5.

Stage 2 Multistep Transformations Problem Set Sequence.

Problem set	Term property	Exponent property	Concepts
7a-d	Positive	Positive and negative fractions	Exponents to roots, negative exponent rule
8a-c	Positive	Positive	Power rule
9a-c	Positive	Negative	Power rule, negative exponent rule
10a-c	Negative	Positive	Power rule, negative sign
11a-c	Positive	Negative	Power rule, negative exponent rule

Research Questions

The main research questions for this study are: To what extent does self-explanation of exponent rules in a game affect their application of exponent rules and perceptions of engagement? To what extent does can game-based practice of exponent rules improve students' application of those exponent rules?

Method

Participants and Design

Participants. The sample comprised 69 participants (19 males, 47 females, 3 unreported) who were ethnically diverse (42 Latino/a, 9 White, 8 Black or African American, 2 Asian or Pacific Islander, 3 Multiracial/multiethnic, and 5 unspecified) and with a mean age of 19.2 years old (*SD* = 3.8 years). When asked how frequently a language other than English is spoken at home, 20 students (29%) reported all or most of the time, 23 (33%) about half of the time, 12 (17%) once in a while, and 11 (16%) never. Eighteen students reported they were repeating the class, 28 students took the preceding course, and 20 students reported this was their first college math course. The mean overall GPA reported by students was 3.16 (SD = 0.47) on a 4.0 scale. When asked about their gameplay skill, 16 students (23%) reported they were very good, 13 (19%) reported good, 24 (35%) reported their skill as fair, and 13 (19%) reported poor gameplay skills. When asked how many hours per week they spend playing games, 26 participants (38%) reported 0 hours, 29 participants (42%) reported 1-4 hours, 7 participants reported 5-8 hours, and 1 participant report 13 or more hours. Finally, the mean score (on a 1 to 4 point scale) for participants' interest in math and math self-efficacy were M = 2.48 (SD = 0.71) and M = 2.5 (SD = 0.75). Overall, the sample appeared to be of average achievement, ethnically diverse, and have a moderate degree of game experience. Participants' interest and self-efficacy were at the scale midpoints and normally distributed, suggesting the sample was not overly interested or disinterested in math, nor excessively possess high or low in math self-efficacy.

Design. A two-group, pretest-posttest experimental design was used. Participants were randomly assigned to either a baseline game condition or a self-explanation condition.

Measures

Prerequisite knowledge. Four questions were asked to gather information on participants' proficiency with basic fraction addition, multiplication, and order of operations.

Rules of exponent. Three scales were developed to measure three skills: (a) converting an exponent to its root form (ETR), (b) application of the negative exponent rule (NER), and (c) application of the power rule (PR). A fourth scale was developed to examine transfer performance (XFER) and included topics from each of the other scales but the problems were more complex in terms of the number of variables in the expressoin. The ETR scale had 8 items (pretest $\alpha = .73$; posttest $\alpha = .74$), NER scale 6 items (pretest $\alpha = .60$; posttest $\alpha = .73$), the PR scale had 4 items (pretest $\alpha = .82$; posttest $\alpha = .65$), and the XFER scale had 5 items (posttest-only $\alpha = .71$).

Game perception. Two scales were used to measure participants' perception of their game experience. The engagement scale (*I really got into the game, Doing the game was boring, I would have liked to play longer*, *I thought the game was a waste of time, Beating the different levels made me feel good*) and a perceived learning scale (*I learned something new about exponents/roots/math from the game*, *The game helped me figure out something I previously had trouble with*, *I realized I had a misconception about an exponent/root topic while playing the game*). The 5-item perceived engagement scale $\alpha = .75$ and 3-item perceived learning scale $\alpha = .85$.

Feedback about the game. Participants were asked to provide feedback about their experience with the game. Participants were asked three questions (*How do you think this game compares to other ways of practicing math (e.g., doing problems on paper)?; How helpful (for learning) do you think it was to emphasize the "next step" in the problem solving process? Overall, how much did you learn about exponents/roots from the game?)*. Each question had Likert-type anchors as well as space for written comments.

Background. Participants were asked to complete a questionnaire asking for their age, gender, ethnicity, and frequency of speaking a language other than English at home. In addition, participants self-reported their overall GPA, transfer status, skill with video games, and number of hours per week spent playing games. Participants were also asked about their interest in math and math self-efficacy. These scales were adopted from Marsh, Hau, Artlet, Baumert, and Peschar (2006). The interest in math scale had 3 items ($\alpha = .72$) and math self-efficacy scale 3 items ($\alpha = .80$).

Game

Base version. The base version was the game as described earlier. There were 24 levels requiring single-step transformations (Stage 1) and 16 levels require multiple-step transformations (Stage 2). Students were not required to self-explain their selections.

Experimental version. The experimental version of the game required participants to engage in self-explanation during selected levels in Stage 1. There were 6 levels that required self-explanation. There were 4 levels in a problem set. The design of the levels within a problem set was to first provide a level that provided minimal feedback to participants if they selected an incorrect step. Then a level with a similar problem was presented except with a self-explanation prompt appearing immediately after the student dropped the next step tile onto target tile on the game board. No feedback was given to students about the accuracy of their self-explanation. The self-explanation prompt was a list of exponent rules. Participants were instructed to choose the rule that justified their next step as shown in Figure 2.

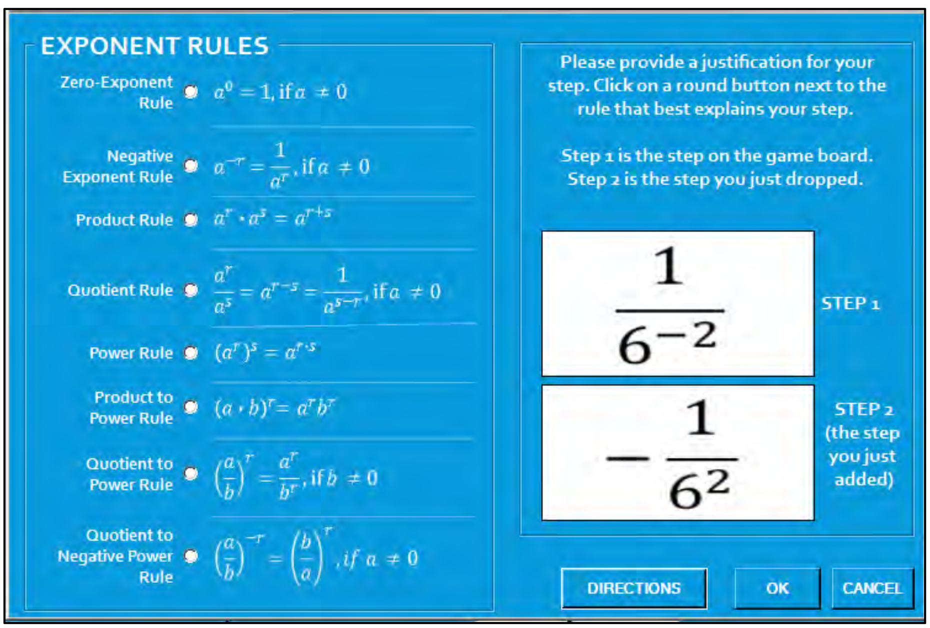

Figure 2. Self-explanation prompt

Procedure

Participants were introduced to the study and then provided all materials (pretest, laptop computer, and posttest). Participants were instructed to start on the pretest. After completing the pretest, the pretest was collected and participants were instructed to start the game on the laptop.

After completing the game at their own pace, participants started the posttest and completed the test at their own pace. All participants except 2 finished all materials. These two participants did not finish the game nor the posttest.

Results

Preliminary Analyses

A check for differences between conditions was conducted for the pretest and background measures. An independent *t*-test was conducted on the prerequisite knowledge items, the three rules of exponent scales, the two attitudinal scales, and the two game experience questions. There were no differences between conditions on any measure ($p > .05$) suggesting that the randomization procedure worked.

Descriptive Statistics

Table 6

Descriptive Statistics for Math Scales by Condition and Occasion

	Total			Self-explanation			Control		
Scale	*N*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Pre-requisite knowledge[a]									
Multiplying two fraction: $\frac{2}{3} \times \frac{1}{2}$	69	.74	.44	33	.76	.44	36	.72	.45
Negative sign and order of operations: $-(-2)^2$	69	.75	.43	33	.82	.39	36	.69	.47
Adding a two fractions: $\frac{2}{5} + \frac{3}{10}$	69	.83	.38	33	.91	.29	36	.75	.44
Negative sign and order of operations: $-16^{\frac{1}{4}}$	69	.12	.32	33	.06	.24	36	.17	.38
Converting an exponent to its root form (ETR)[b]									
Pretest	69	3.00	1.77	33	3.33	1.57	36	2.69	1.91
Posttest	67	4.33	1.93	31	4.39	1.65	36	4.28	2.16
Applying the negative exponent rule (NER)[c]									
Pretest	69	2.55	1.57	33	2.21	1.32	36	2.86	1.73
Posttest	67	3.27	1.85	31	3.16	1.59	36	3.36	2.06
Applying the power rule (PR)[d]									
Pretest	69	2.49	1.56	33	2.45	1.56	36	2.53	1.58
Posttest	67	3.15	1.12	31	3.32	1.05	36	3.00	1.17
Transfer (XFER)[e]	67	2.06	1.52	31	2.19	1.42	36	1.94	1.60

Note. [a]Min. = 0, Max. = 1. [b]Min. = 0, Max. = 8. [c]Min. = 0, Max. = 6. [d]Min. = 0, Max. = 4. [e]Min. = 0, Max. = 5.

Main Analyses

Performance. Separate repeated-measures ANOVAs were conducted on the ETR, NER, and PR scales. To simultaneously determine if there was a condition effect as well as a learning effect, participants performance were analyzed with a 2(condition) × 2(occasion) ANOVA, with occasion as the within-subjects factors, and condition as the between-subjects factor. No significant condition × occasion interaction was found for ETR, NER, or PR scales, suggesting that there were no effects of self-explanation on participants' learning of those topics. For the transfer task, an independent *t*-test was conducted on the XFER scale to test for differences between conditions. No differences were found.

However, a significant within-subjects main effect of occasion was found for ETR (*F*[1, 65] = 12.82, *MSE* = 1.12, p = .001), NER (*F*[1, 65] = 19.42, *MSE* = 17.16, $p < .001$), and PR (*F*[1, 65] = 12.82, *MSE* = 14.13, p = .001), suggesting that participants learned over the course of the game. Table 7 displays the descriptive statistics, effect size of the change (Dunlap, Cortina, Vaslow, & Burke, 1996), and percent increase for each scale. The largest increase was found for the exponent to root transformation problems.

Table 7.

Learning Effects of the Game by Topic

		Pretest		Posttest			
Scale	*n*	*M*	*SD*	*M*	*SD*	*d*	% increase
Converting an exponent to its root form (ETR)[a]	67	3.00	1.72	4.33	1.93	0.73	44.3
Applying the negative exponent rule (NER)[b]	67	2.57	1.58	3.27	1.85	0.40	27.3
Applying the power rule (PR)[c]	67	2.51	1.54	3.15	1.12	0.47	25.6

Note. [a]Min. = 0, Max. = 8; [b]Min. = 0, Max. = 6; [c]Min. = 0, Max. = 4.

Perceived learning and engagement. To examine the effects of self-explanation on participants' perceived engagement, an independent *t*-test was conducted to test the effects of condition on perceived learning and participants' perceived engagement. No differences were found for participants' perceived learning. However, participants who received the self-explanation prompts (*M* = 3.07 *SD* = 0.56), compared to participants who did not receive self-explanation prompts (*M* = 2.68, *SD* = 0.58), had significantly lower ratings of their experience, $t(63) = 2.73$, $p = .008$, $d = 0.68$. The large effect size suggests that the self-explanation prompts interfered with participants' perceived engagement with the game.

Usability. The last analysis examined participants' perceptions of their experience. Table 8 shows the frequency of responses to three questions: (a) How do you think this game compares to other ways of practicing math (e.g., doing problems on paper)? (b) How helpful (for learning) do you think it was to emphasize the "next step" in the problem solving process? and (c) Overall, how much did you learn about exponents/roots from the game?

Table 8.

Participants' Utility Ratings (N = 64)

Question	Response Anchors				
How do you think this game compares to other ways of practicing math (e.g., doing problems on paper)?	Much less effective	Less effective	Similar	More effective	Much more effective
	3	7	16	27	11
How helpful (for learning) do you think it was to emphasize the "next step" in the problem solving process?	Extremely helpful	Very helpful	Helpful	Somewhat helpful	Not helpful at all
	11	10	25	17	1
Overall, how much did you learn about exponents/roots from the game?	A lot	Some	Not much at all		
	17	43	4		

Overall, participants reported very favorable responses to the game, with 59% of the same reporting the game was more or much more effective than other ways of practicing math. This is remarkable considering the game was in a pre-prototype stage, did not mask the mathematics, and provided minimal game garnishes. Thirty-three percent of students reported the emphasis of the next step as being very or extremely helpful for learning, with an additional 39% reporting the emphasis on "next steps" as helpful. Finally, 27% of students reported the game as helping them learn a lot about exponents/roots and 67% reporting the game help them some.

Conclusion

Overall, the pre-prototype game appeared to provide students with an engaging and beneficial experience. With less than 40 minutes of gameplay time, students improved their performance on math problems related to converting an exponent to its root form, applying the negative exponent rule, and applying the power rule, and reported high levels of utility. This is an interesting finding because it suggests that the instructional sequence, game mechanics, and focus on problems susceptible to common errors collectively helped students improve their performance substantially, as indicated by the moderate to large pretest-to-posttest effects sizes ranging from .40 to .73.

The lack of finding an effect of the self-explanation prompts is curious. We followed the similar procedures used by Mayer and Johnson (2010) and Johnson and Mayer (2013), who found that the when people are asked to select self-explanations for their moves in a game, they learn more (compared to people who are not asked to select an explanation). Our results are more in line with O'Neil et al. (2014), who found no main effect of self-explanation in math learning in a game.

O'Neil et al. concluded that the most effective self-explanations where those that prompted connections between the concrete elements in the game and the abstract mathematics terminology. The least effective self-explanation prompts were those that asked very simple or very abstract questions. It may be the case for our game and participants, the self-explanation prompts may been too abstract as the choices were the symbolic representation of the exponent rule. Further research is needed to explore this issue.

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Chung, G. K. W. K., & Delacruz, G. C. (2014). Cognitive readiness for solving equations. In H. F. O'Neil, R. S. Perez, & E. L. Baker (Eds.), *Teaching and measuring cognitive readiness* (pp. 135–148). New York, NY: Springer.

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. (1996). Meta-analysis of experiements with matched groups or repeated measures design. *Psychological Methods*, *1*, 170-177.

Johnson, C. L.m & Mayer, R. E. (2013). Applying the self-explanation principle to multimedia learning in a computer-based game-like environment. *Computers in Human Behavior*, 26, 1246–1252

Marsh, H. W., Hau, K. T., Artlet, C., Baumert, J., & Peschar, J. L. (2006). OECD's brief self-report measure of educational psychology's most useful affective constructs: Cross-cultural, psychometric comparisons across 25 countries. *International Journal of Testing, 6*, 311–360.

Mayer, R. E., & Johnson, C. L. (2010). Adding instructional features that promote learning in a game-like environment. *Journal of Educational Computing Research, 42*, 241–265.

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Appendix P1-A

Common Student Errors and Difficulties

Type	**Examples**	
Fundamentals	Poor understanding of grouping symbols (e.g., parentheses), order of operations, fractions, distribution, equality. Examples of rare but illustrative common errors:	
	$(x+y)^2 \Rightarrow x^2+y^2$	Distributing the exponent.
	$\frac{\sqrt{2}}{\sqrt{3}} \Rightarrow \frac{2}{3}$	Canceling the radical.
	$\frac{\sin(2x)}{2} \Rightarrow \frac{\sin(x)}{1}$	Canceling the 2.
	$\frac{\sqrt{2}}{2} \Rightarrow \sqrt{\ }$	Canceling the 2.
	$\frac{2}{3}+\frac{3}{5} \Rightarrow \frac{5}{8}$	Adding the numerators (and denominators) together (i.e., across the fraction bar).
Notation	Unfamiliarity with symbols and their meanings	

Radicals and exponents (laws of exponents)	$(-4)^{\frac{3}{2}}$	Negative numbers raised to some power are perceived as difficult, with students perceiving the expression as being too complicated or too many things to do.
	$\sqrt[8]{16^4}$	Difficulty decomposing or breaking the problem into sub-parts.
	$-16^{\frac{1}{4}}$	Difficulty remembering the convention (i.e., $(-16)^{\frac{1}{4}}$) and will interpret the expression as $-(16^{\frac{1}{4}})$.
	$\frac{1}{8^{-\frac{1}{3}}}$ same as $\frac{1}{-8^{\frac{1}{3}}}$ same as $-8^{\frac{1}{3}}$	Misapplication of laws of exponents.

Type	Examples
Motivation	Students often will ask instructors to just tell them how to solve the problem. Students often lack confidence in their capabilities to learn math. Students also appear to respond positively to instructor feedback (e.g., use of "smiley" faces to indicate good job).
Problem solving	Often needs help with the first step. Students often lack the skills in strategizing about the problem solving process. Students will often appear to make up their own rules, ignore rules, confuse rules.

Appendix P1-B
Background Information

GENERAL INFORMATION

1. Age: ______ years

2. Gender: ❑ Male ❑ Female

3. Ethnicity:

❑ Biracial/multiethnic
❑ African American
❑ Asian American
❑ Latino
❑ Native American
❑ White, non-Hispanic
❑ Other _______________

4. Academic standing: ❑ Freshman ❑ Sophomore ❑ Junior ❑ Senior ❑ Other ______________

5. Overall GPA: ______

6. Major GPA: ______

7. SAT I Verbal Score: ______ ❑ N/A
8. ACT Verbal Score: ______ ❑ N/A
9. SAT I Math Score: ______ ❑ N/A
10. ACT Math Score: ______ ❑ N/A

Appendix P1-C
Language Background Information

1. How good are you at reading English?

   ❑ Very good ❑ Good ❑ Average ❑ Poor

2. Do you speak a language besides English?
   ❑ Yes ❑ No

If NO, skip to the page titled **<PAGE TITLE HERE>**

If YES, what is that language? ________________________________

. **If YES**, please fill out the next page.

		Always	Most of the time	Some-times	Never
3.	How much do you speak that language with your parents?	❑	❑	❑	❑
4.	How much do you speak that language with your friends at school and outside of school?	❑	❑	❑	❑

		Very well	Moder-ately well	Fairly well	Not very well
5.	Do you speak that language well?	❑	❑	❑	❑
6.	Do you understand that language well?	❑	❑	❑	❑
7.	Do you read that language well?	❑	❑	❑	❑
8.	Do you write that language well?	❑	❑	❑	❑
9.	Do you understand spoken English well?	❑	❑	❑	❑
10.	Do you speak English well?	❑	❑	❑	❑
11.	Do you read English well?	❑	❑	❑	❑
12.	Do you write English well?	❑	❑	❑	❑

13. In which language do you read better?
❑ English ❑ Other language

14. If you have homework that you don't understand, and you need to ask a friend about it, what language would you prefer to use?
❑ English ❑ Other language

Appendix P1-D
Perceptions of Math Questionnaire

	Disagree	Disagree somewhat	Agree somewhat	Agree
1. I get good marks in mathematics.	❑	❑	❑	❑
2. Mathematics is one of my best subjects.	❑	❑	❑	❑
3. I have always done well in mathematics.	❑	❑	❑	❑
4. When I do mathematics, I sometimes get totally absorbed.	❑	❑	❑	❑
5. Because doing mathematics is fun, I wouldn't want to give it up.	❑	❑	❑	❑
6. Mathematics is important to me personally.	❑	❑	❑	❑

Marsh, H. W., Hau, K-T., Artelt, C., Baumert, J., & Peschar, J. L. (2006). OECD's brief self-report measure of educational psychology's most useful affective constructs: Cross-cultural, psychometric comparisons across 25 countries. *International Journal of Testing, 6*, 311–360.

Appendix P1-E
Example Types of Math Problems

*n*th Roots

$\sqrt{9}+\sqrt{16}$

$z^{\frac{1}{2}}$

$\left(\frac{x^2y}{xy^{-2}}\right)^{-3}$

$(6a)^{-\frac{5}{4}}$

$\sqrt[3]{64}$

$\left(\frac{2a^2}{b^{-1}}\right)^3$

$-\sqrt[6]{(-3)^6}$

Exponents

$$\sqrt[8]{16^4}$$

$$\left(\frac{64m^{\frac{1}{2}}n}{m^{-2}n^{\frac{4}{3}}}\right)^{\frac{1}{2}}$$

$$\frac{\sqrt{6}}{\sqrt[4]{36}}$$

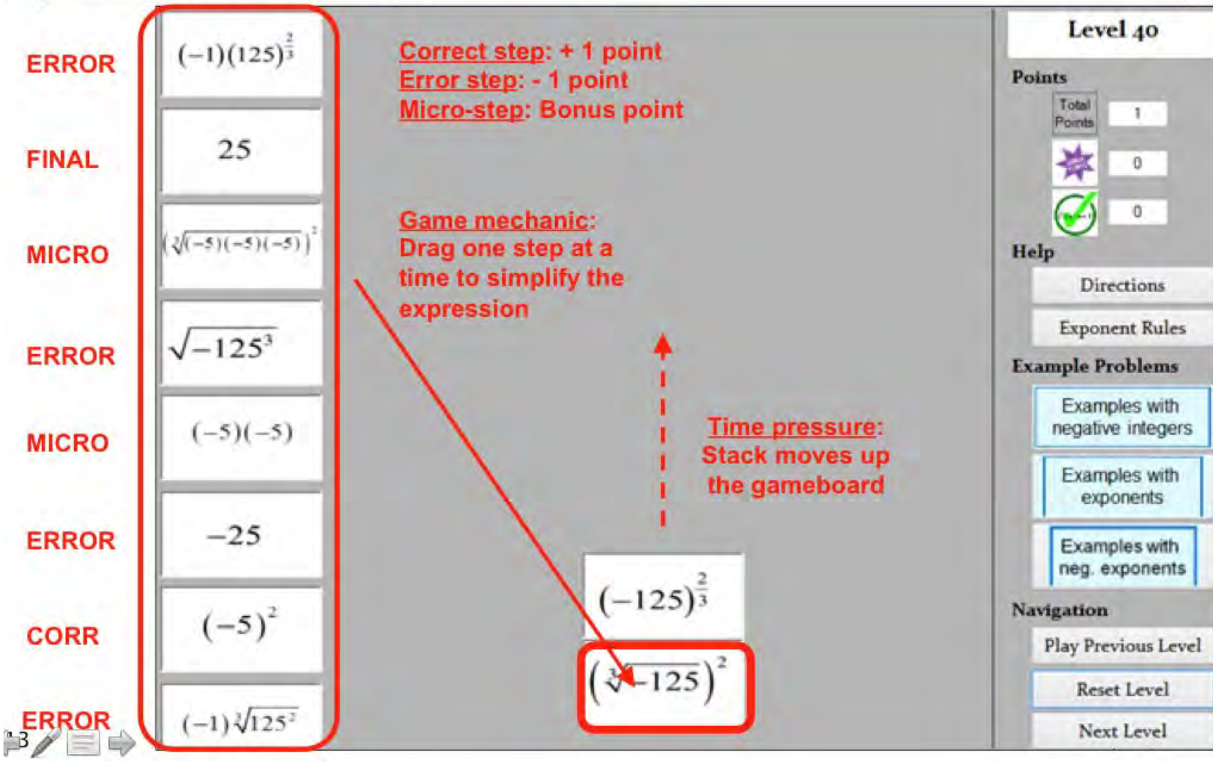
$$\left(\frac{27x^{\frac{1}{2}}y^{-1}}{y^{-\frac{2}{3}}x^{-\frac{1}{2}}}\right)^{\frac{1}{3}} - \left(\frac{4x^{\frac{1}{3}}y^{\frac{4}{9}}}{x^{-\frac{1}{3}}y^{\frac{2}{3}}}\right)^{\frac{1}{3}}$$

$$9^{-\frac{5}{4}} \times 9^{\frac{1}{3}}$$

Appendix P2-A

Example Screenshot of Prototype

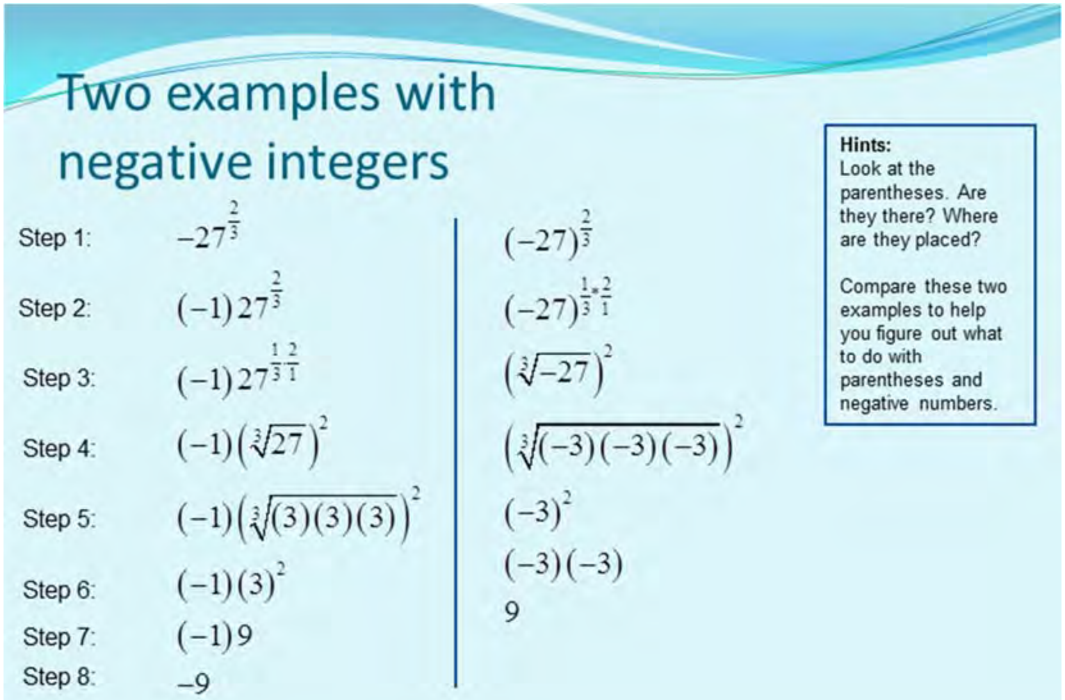
Pre-prototype Game



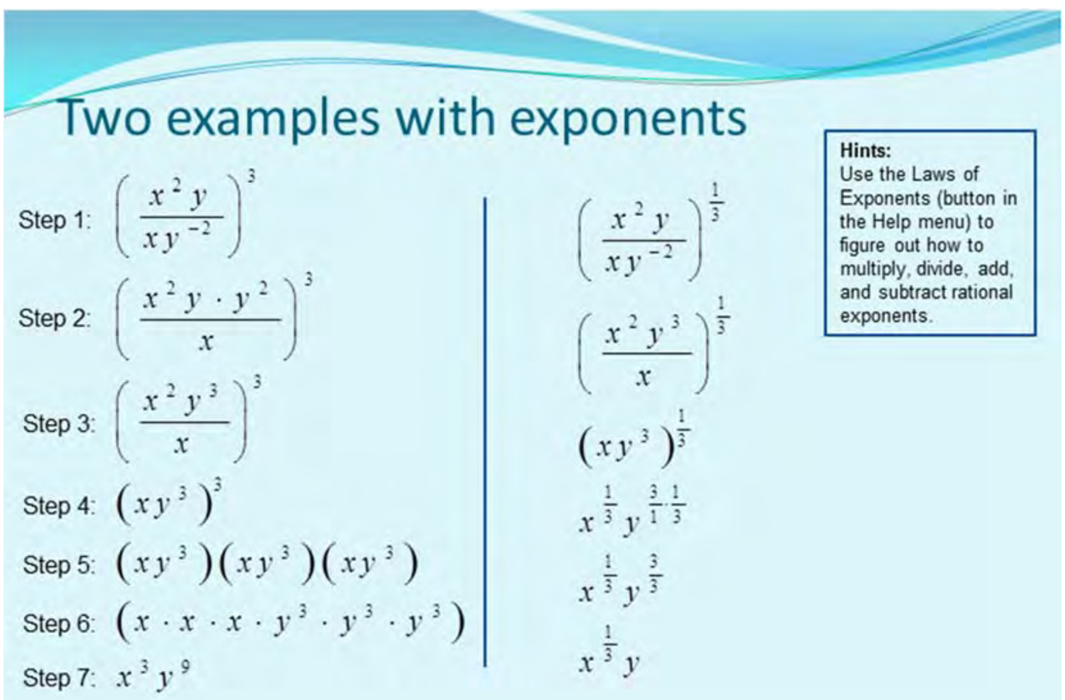
Appendix P2-B

Feedback and Help

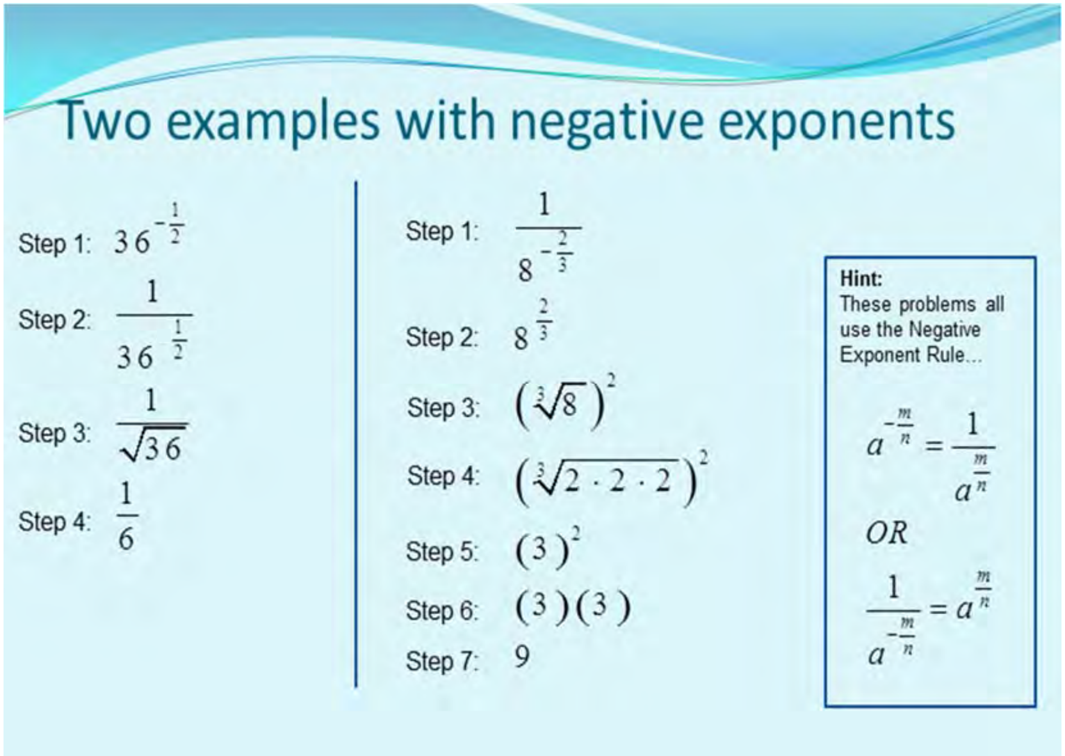
Help: Negative integers



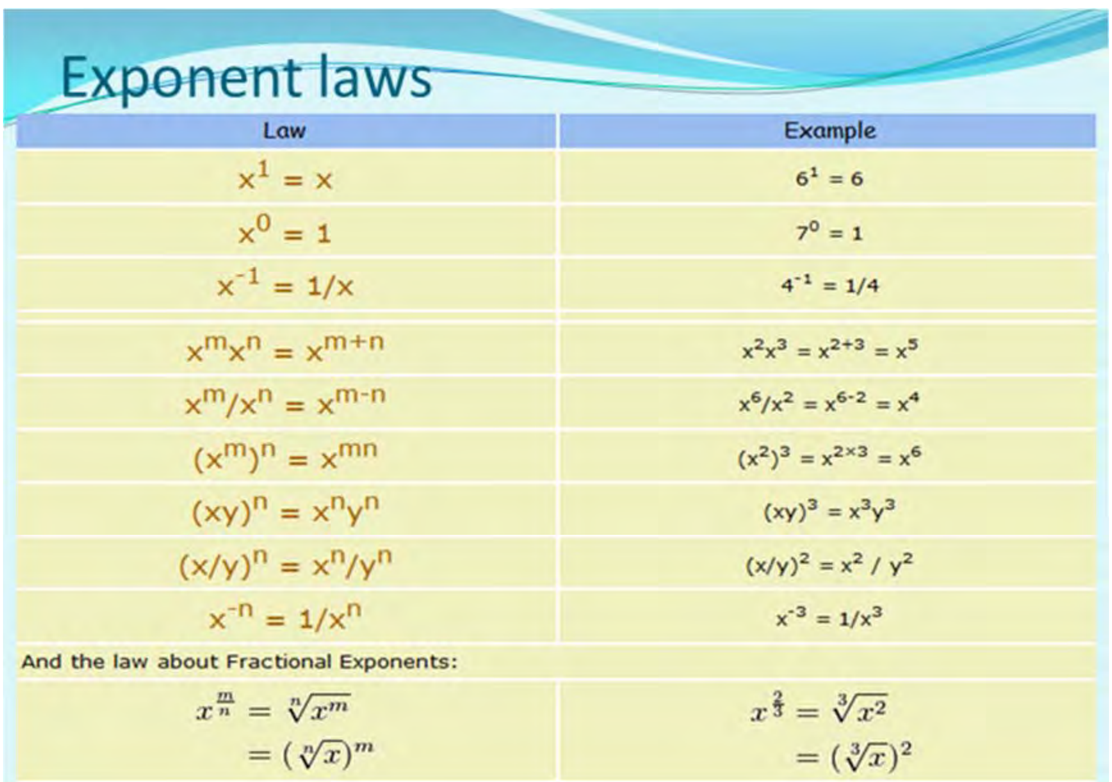
Help: Positive exponents



Help: Negative exponents



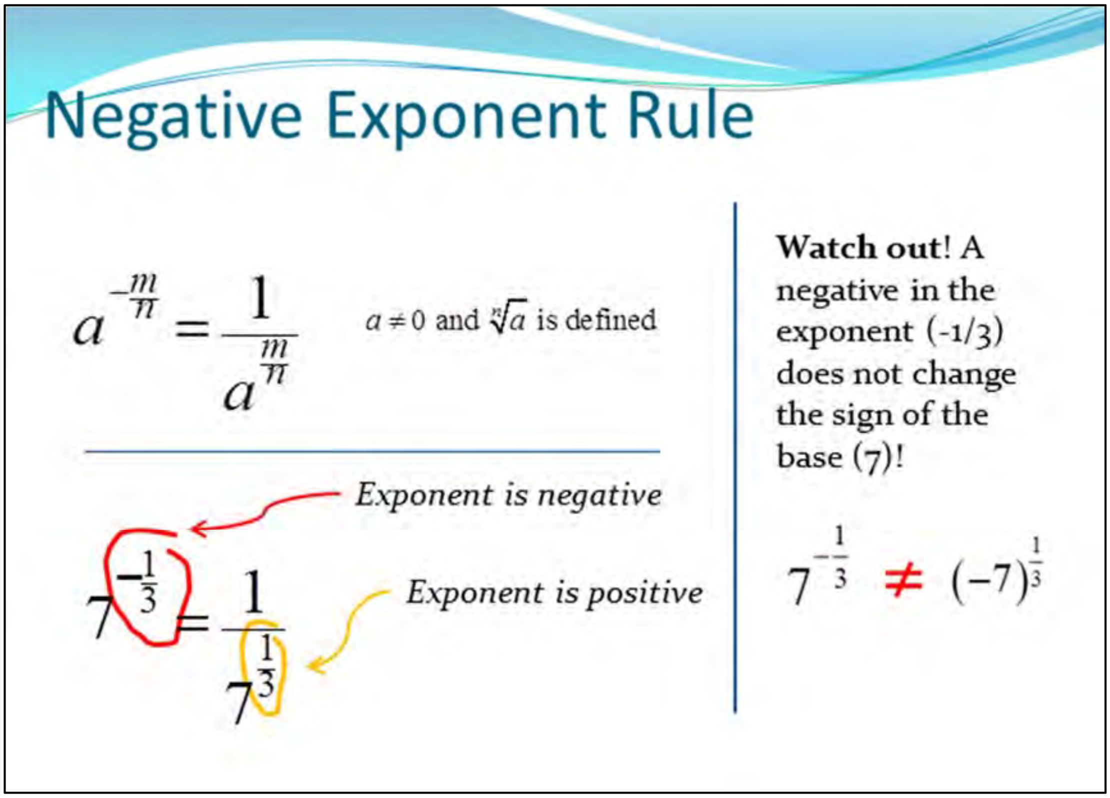
Exponent Laws


Exponent laws

Law	Example
$x^1 = x$	$6^1 = 6$
$x^0 = 1$	$7^0 = 1$
$x^{-1} = 1/x$	$4^{-1} = 1/4$
$x^m x^n = x^{m+n}$	$x^2x^3 = x^{2+3} = x^5$
$x^m/x^n = x^{m-n}$	$x^6/x^2 = x^{6-2} = x^4$
$(x^m)^n = x^{mn}$	$(x^2)^3 = x^{2\times3} = x^6$
$(xy)^n = x^n y^n$	$(xy)^3 = x^3y^3$
$(x/y)^n = x^n/y^n$	$(x/y)^2 = x^2 / y^2$
$x^{-n} = 1/x^n$	$x^{-3} = 1/x^3$
And the law about Fractional Exponents:	
$x^{\frac{m}{n}} = \sqrt[n]{x^m} = (\sqrt[n]{x})^m$	$x^{\frac{2}{3}} = \sqrt[3]{x^2} = (\sqrt[3]{x})^2$

Feedback Images

Example Feedback in Game: Negative Exponent rule



Example Feedback in Game: *n*th roots

Change the fractional exponent to an *n*th root expression.

$$\left(\sqrt[n]{a}\right)^m = a^{\frac{m}{n}} = \sqrt[n]{a^m} \quad \text{provided } \sqrt[n]{a} \text{ exists.}$$

$$\left(\sqrt[3]{7}\right)^4 = 7^{\frac{4}{3}} = \sqrt[3]{7^4}$$

Change the fractional exponent to an *n*th root expression.

$$a^{-\frac{m}{n}} = \frac{1}{a^{\frac{m}{n}}} \quad a \neq 0 \text{ and } \sqrt[n]{a} \text{ is defined}$$

$$9^{-\frac{3}{5}} = \frac{1}{9^{\frac{3}{5}}}$$

Use the Negative Exponent Rule to get this form

$$a^{\frac{m}{n}} = \sqrt[n]{a^m} = \left(\sqrt[n]{a}\right)^m$$

Transform to <u>nth root form</u>

$$9^{\frac{3}{5}} = \sqrt[5]{9^3} = \left(\sqrt[5]{9}\right)^3$$

$$\frac{1}{a^{\frac{m}{n}}} = \frac{1}{\sqrt[n]{a^m}} = \frac{1}{\left(\sqrt[n]{a}\right)^m}$$

Don't forget the original form is a fraction

$$\frac{1}{9^{\frac{3}{5}}} = \frac{1}{\sqrt[5]{9^3}} = \frac{1}{\left(\sqrt[5]{9}\right)^3}$$

Appendix P2-C

Example of Instructional Variation

Focus on Step-to-step Transitions

Micro-steps | **Typical steps** | **Common errors**

$(-125)\uparrow 2/3$

$(\surd 3\&-125\ )\uparrow 2$

$(\surd 3\&(-5)(-5)(-5)\ )\uparrow 2$

$(-5)\uparrow 2$

$(-5)(-5)$

25

Common errors:

$(-1)(125)\uparrow 2/3$

$\surd -125\uparrow 3$

$-\surd 3\&-125\uparrow 2$

-25

Appendix P2-D

Data Analysis

Table 1

Attitudes Towards Math by Condition

	Control (n= 57)	Treatment (n=54)	df	t
Pretest	4.74(2.00)	4.98 (2.28)	109	.60
Interest in math	2.52 (.66)	2.26 (.59)	105	2.09*
Self-belief in math	2.24 (.77)	2.13 (.84)	108	.70
GPA	2.99 (.76)	3.25 (.58)	92	1.87
Hrs week videogames	2.07(1.07)	2.37(3.01)	109	.71
Skill videogames	2.56(.95)	2.46(.95)	109	.55

*p < .05.

Table 2

Math Achievement by Condition

	Number of Items	Control (n= 57)	Treatment (n=54)	Total (n=111)
Pretest Core	7	2.39 (1.41)	2.44 (1.67)	2.41 (1.53)
Posttest Core	7	3.16 (1.75)	3.26 (1.73)	3.21 (1.73)
Pretest-posttest Core change		.77	.82	.80
Percent improvement		11%	12%	11%

Table 3

Item Analysis

	Pretest		Posttest				
	n	%	n	%	Positive change (frequency)	Negative change (frequency)	Neutral (frequency)
Item 5							
Incorrect	89	80	46	41	**45**	**2**	**64****
Correct	22	20	65	59			
Item 6							
Incorrect	39	35	39	35	12	12	87
Correct	72	64	72	65			
Item 7							
Incorrect	47	42	52	47	20	25	66
Correct	64	58	59	53			
Item 8							
Incorrect	57	51	56	50	19	18	74
Correct	54	49	55	50			
Item 9							
Incorrect	76	69	65	59	19	8	84
Correct	35	31	46	41			
Item 10							
Incorrect	97	87	69	62	**32**	**4**	**75****
Correct	14	13	42	38			
Item 11[a]							
Incorrect	104	93	93	84	**14**	**4**	**92***
Correct	7	6	17	15			

[a] One student missing

* $p < .05$, ** $p < .01$

Appendix P3-A:

Analysis of the Errors Committed by 30 or More Students

No.	Image ID (given/ next step)	Given Step	Next Step	Concept	Term Property
1	301/351 (n = 61)	$-16^{\frac{3}{4}} - \sqrt[5]{32}$	$\left(\sqrt[4]{-16}\right)^{3} - \sqrt[5]{32}$		Negative Terms Outside Parentheses/Root
2	3101/3151 (n = 58)	$3^{\frac{1}{3}} \cdot 3^{\frac{1}{3}}$	$9^{\frac{1}{9}}$	Product Rule	Term Operations Mult/Div
3	3101/3152 (n = 57)	$3^{\frac{1}{3}} \cdot 3^{\frac{1}{3}}$	$3^{\frac{1}{9}}$	Product Rule	
4	303/351 (n = 54)	$(-1)\left(\sqrt[4]{16}\right)^{3} + (-1)\sqrt[5]{32}$	$\left(\sqrt[4]{-16}\right)^{3} - \sqrt[5]{32}$		Negative Terms Outside Parentheses/Root
5	301/354 (n = 48)	$-16^{\frac{3}{4}} - \sqrt[5]{32}$	$\left(\sqrt[3]{-16}\right)^{4} - \sqrt[5]{32}$		Negative Terms Outside Parentheses/Root
6	103/150 (n = 43)	$\left(4^{\frac{1}{2}}\right)\left(a^{\frac{2}{2}}\right)\left(b^{-\frac{3}{4}}\right)$	$4\left(a^{\frac{2}{1}\cdot\frac{1}{2}}\right)\left(b^{-\frac{3}{2}\cdot\frac{1}{2}}\right)$		Exp Term Type On Integer
7	303/352 (n = 43)	$(-1)\left(\sqrt[4]{16}\right)^{3} + (-1)\sqrt[5]{32}$	$(-1)\left(\sqrt[3]{16}\right)^{4} + (-1)\sqrt[5]{32}$		

8	303/354 (n = 43)	$\left(4^{\frac{1}{2}}\right)\left(a^{\frac{2}{2}}\right)\left(b^{-\frac{3}{4}}\right)$	$\frac{2a}{b^{-\frac{3}{4}}}$	Negative Exponent Rule	
9	4801/4852 (n = 42)	$(27b)^{\frac{2}{3}} + \left(4b^{\frac{1}{3}}\right)^2$	$\left(\sqrt[3]{27}\right)^2 b^{\frac{2}{3}} + 16b^{\frac{1}{3}+2}$	Power Rule	
10	1403/1452 (n = 42)	$x^{\frac{2}{3}}y^{-1}x^{-\frac{2}{3}}y^{\frac{1}{3}}$	$\left(\frac{x^{\frac{2}{3}}y^{\frac{1}{2}}}{x^1y^1}\right)^{\frac{2}{3}}$	Power Rule	
11	4502/4552 (n = 42)	$(27)^{\frac{2}{3}}\left(b^6\right)^{\frac{2}{3}}$	$\left(\sqrt[3]{27}\right)^2\left(b^{6+\frac{2}{3}}\right)$	Power Rule	
12	2201/2204 (n = 41)	$\left(\frac{x^2y}{y^{-2}}\right)^3$	$\left(x^2y^3\right)^3$		No Error: Missed Steps
13	4801/4851 (n = 41)	$(27b)^{\frac{2}{3}} + \left(4b^{\frac{1}{3}}\right)^2$	$27b^{\frac{2}{3}} + 4b^{\frac{1}{3}\cdot 2}$	Power Rule	
14	2203/2206 (n = 40)	$\left(x^2y^{1+2}\right)^3$	x^6y^9		No Error: Missed Steps
15	103/151 (n = 37)	$\left(4^{\frac{1}{2}}\right)\left(a^{\frac{2}{2}}\right)\left(b^{-\frac{3}{4}}\right)$	$\left(4^{\frac{1}{2}}\right)\left(a^{\frac{3}{2}}\right)\left(b^{-\frac{4}{2}}\right)$		Uncategorized Error: Changed Exponents

16	4602/4652 (n = 37)	$(9)^{\frac{1}{2}}\left(b^{-\frac{3}{2}}\right)^{\frac{1}{2}}$	$(9)^{\frac{1}{2}}\left(b^{-\frac{3}{2}+\frac{1}{2}}\right)$	Power Rule	
17	3501/3551 (n = 36)	$\sqrt[3]{x^3}$	$\lvert x \rvert$	Simplifying Roots	Term Type Variable
18	301/352 (n = 35)	$-16^{\frac{3}{4}}-\sqrt[5]{32}$	$(-1)\left(\sqrt[3]{16}\right)^4+(-1)\sqrt[5]{32}$		
19	1203/1253 (n = 35)	$(-1)9^{\frac{3}{2}}+27^{\frac{2}{3}}$	$(-1)\left(\sqrt[3]{9}\right)^2+\left(\sqrt{27}\right)^3$		
20	3401/3451 (n = 34)	$\sqrt{x^2}$	x	Simplifying Roots	Term Type Variable
21	1203/1254 (n = 33)	$(-1)9^{\frac{3}{2}}+27^{\frac{2}{3}}$	$\left(\sqrt[3]{-9}\right)^2+\left(\sqrt{27}\right)^3$		Negative Terms Outside Parentheses/Root
22	303/302 (n = 32)	$(-1)\left(\sqrt[4]{16}\right)^3+(-1)\sqrt[5]{32}$	$(-1)16^{\frac{3}{4}}+(-1)\sqrt[5]{32}$		No Error: Backwards Step Order
23	1402/1451 (n = 31)	$x^{\frac{2}{3}}y^{-1}\left(x^{-1}\right)^{\frac{2}{3}}\left(y^{\frac{1}{2}}\right)^{\frac{2}{3}}$	$\left(x^{\frac{2}{3}}y^{-1}x^{-1}y^{\frac{1}{2}}\right)^{\frac{2}{3}}$	Power Rule	

24	4301/4351 (n = 31)	$\frac{1}{9^{-\frac{1}{2}}}$	$\sqrt[2]{-9}$	Negative Exponent Rule
25	1202/1252 (n = 30)	$-9^{\frac{3}{2}}+27^{\frac{2}{3}}$	$\left(\sqrt{-9}\right)^{3}+\left(\sqrt[3]{27}\right)^{2}$	Negative Terms Outside Parentheses/Root

Appendix P3-B:
All Errors Committed by All Students

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
61	45	301	351	1	2	1	1	1	2
58	21	3101	3151	1	2	1	1	1	2
57	21	3101	3152	1	3	1	2	1	1
54	45	303	351	1	4	1	2	1	2
48	45	301	354	1	6	1	3	1	3
43	44	103	150	1	6	1	2	1	3
43	45	303	352	1	6	1	3	1	2
43	45	303	354	1	9	1	5	1	3
42	44	103	152	1	9	1	4	1	3
42	48	4801	4852	1	4	1	2	1	2
42	49	1403	1452	1	4	1	3	1	2
41	41	4502	4552	1	4	1	2	1	2
41	43	2201	2204	1	2	1	1	1	2
40	48	4801	4851	1	2	1	1	1	2
37	43	2203	2206	1	2	1	2	1	1
37	44	103	151	1	8	1	3	1	2
36	42	4602	4652	1	4	1	2	1	2

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
35	20	3501	3551	1	2	1	1	1	2
35	45	301	352	1	4	1	2	1	2
34	47	1203	1253	1	9	1	4	1	3
33	19	3401	3451	1	3	1	1	1	3
32	47	1203	1254	1	12	1	5	1	3
31	45	303	302	1	2	1	1	1	2
31	49	1402	1451	1	2	1	1	1	2
30	38	4301	4351	1	2	1	1	1	2
30	47	1202	1252	1	3	1	2	1	2
29	49	1401	1451	1	2	1	1	1	2
29	49	1402	1452	1	3	1	2	1	1
29	49	1403	1453	1	6	1	4	1	2
28	47	1203	1252	1	6	1	3	1	2
28	48	4803	4851	1	2	1	1	1	2
27	40	4401	4451	1	2	1	1	1	2
27	49	1404	1452	1	4	1	3	1	2
26	34	4201	4251	1	1	1	1	1	1
26	44	102	151	1	3	1	2	1	2
26	44	103	153	1	11	1	5	1	2
26	46	2303	2354	1	7	1	6	1	2
26	47	1201	1252	1	3	1	2	1	2
26	49	1403	1451	1	4	1	2	1	2
26	49	1404	1453	1	5	1	4	1	3
25	41	4501	4552	1	3	1	2	1	2
25	44	101	151	1	2	1	2	1	1
25	48	4802	4852	1	4	1	2	1	3
24	23	3301	3351	1	2	1	1	1	2
24	42	4603	4652	1	6	1	3	1	3
24	44	103	102	1	3	1	1	1	3
24	48	4802	4851	1	1	1	1	1	1
23	36	1301	1353	1	3	1	3	1	2
23	42	4601	4652	1	3	1	2	1	2
23	47	1204	1252	1	9	1	3	1	4
23	49	1406	1454	1	4	1	4	1	1

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
23	49	1406	1455	1	6	1	5	1	2
22	36	1303	1353	1	4	1	4	1	2
22	39	1101	1155	1	9	1	5	1	2
22	41	4501	4551	1	2	1	1	1	2
22	43	2201	2206	1	3	1	2	1	1
22	47	1201	1251	1	2	1	1	1	2
22	49	1401	1452	1	2	1	2	1	2
21	36	1301	1352	1	2	1	2	1	1
21	39	1101	1151	1	4	1	1	1	4
21	41	4503	4552	1	3	1	2	1	2
21	42	4602	4651	1	2	1	1	1	2
21	44	104	153	1	6	1	5	1	2
21	45	302	351	1	3	1	1	1	3
21	47	1201	1254	1	6	1	4	1	2
21	47	1202	1254	1	7	1	4	1	2
21	47	1204	1254	1	15	1	5	1	3
20	14	1701	1751	1	3	1	1	1	3
19	45	302	354	1	7	1	4	1	3
19	47	1204	1253	1	12	1	4	1	3
19	48	4803	4852	1	2	1	2	1	1
19	49	1403	1402	1	3	1	1	1	3
18	11	1501	1551	1	1	1	1	1	1
18	12	2701	2752	1	3	1	2	1	2
18	41	4504	4551	1	2	1	1	1	2
18	42	4603	4651	1	4	1	2	1	2
18	44	101	150	1	1	1	1	1	1
18	45	302	352	1	4	1	2	1	2
18	47	1202	1253	1	5	1	3	1	2
18	49	1404	1451	1	3	1	2	1	1
17	34	4203	4253	1	4	1	3	1	1
17	37	204	251	1	5	1	2	1	5
17	37	204	252	1	7	1	3	1	4
17	37	204	254	1	10	1	5	1	2
17	41	4502	4551	1	2	1	1	1	2

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
17	43	2203	2202	1	2	1	1	1	2
16	35	204	254	1	7	1	4	1	2
16	39	1101	1152	1	6	1	2	1	2
16	39	1102	1152	1	3	1	2	1	2
16	40	4401	4452	1	4	1	2	1	2
16	40	4402	4452	1	4	1	2	1	2
16	42	4604	4652	1	3	1	3	1	1
16	43	2201	2252	1	6	1	4	1	2
16	43	2202	2206	1	2	1	1	1	2
16	43	2203	2251	1	4	1	3	1	2
16	47	1201	1253	1	4	1	3	1	1
16	47	1204	1255	1	17	1	6	1	2
16	48	4805	4851	1	1	1	1	1	1
16	49	1403	1454	1	7	1	5	1	2
15	17	2601	2652	1	2	1	2	1	1
15	44	104	152	1	5	1	4	1	3
14	34	4202	4253	1	3	1	3	1	1
14	36	1303	1302	1	2	1	1	1	2
14	41	4504	4552	1	3	1	2	1	1
14	44	102	150	1	1	1	1	1	1
14	45	303	353	1	7	1	4	1	1
14	47	1204	1251	1	5	1	2	1	3
13	15	1601	1651	1	1	1	1	1	1
13	22	3201	3251	1	1	1	1	1	1
13	35	205	254	1	3	1	3	1	1
13	37	204	253	1	9	1	4	1	2
13	40	4402	4451	1	2	1	1	1	2
13	43	2203	2252	1	5	1	4	1	1
13	47	1203	1202	1	3	1	1	1	3
13	47	1203	1251	1	4	1	2	1	4
12	33	4102	4152	1	3	1	2	1	2
12	35	204	251	1	2	1	1	1	2
12	35	204	252	1	4	1	2	1	2
12	36	1303	1351	1	2	1	2	1	2

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
12	36	1303	1352	1	3	1	3	1	1
12	39	1104	1153	1	3	1	3	1	2
12	41	4503	4551	1	1	1	1	1	1
12	42	4604	4651	1	2	1	2	1	1
12	46	2303	2305	1	3	1	2	1	2
12	46	2303	2352	1	5	1	4	1	2
12	47	1204	1202	1	3	1	1	1	3
12	49	1403	1455	1	9	1	6	1	2
12	49	1404	1402	1	2	1	1	1	2
11	18	2801	2852	1	2	1	2	1	1
11	32	4001	4052	1	2	1	2	1	1
11	32	4003	4051	1	2	1	1	1	2
11	32	4003	4052	1	3	1	2	1	1
11	33	4101	4151	1	1	1	1	1	1
11	33	4101	4152	1	3	1	2	1	2
11	34	4203	4251	1	2	1	1	1	2
11	35	204	253	2	6	1	3	1	2
11	37	205	254	1	6	1	6	1	1
11	38	4302	4351	1	1	1	1	1	1
11	39	1104	1152	1	2	1	2	1	2
11	47	1205	1255	1	3	1	3	1	1
10	13	1801	1851	1	1	1	1	1	1
10	16	2401	2451	1	1	1	1	1	1
10	32	4002	4052	1	5	1	2	1	3
10	33	4102	4151	1	2	1	1	1	2
10	34	4203	4252	1	4	1	2	1	2
10	43	2204	2251	1	2	1	2	1	1
10	43	2204	2252	1	3	1	3	1	1
10	47	1203	1255	3	14	3	6	1	2
10	48	4804	4851	1	1	1	1	1	1
10	49	1405	1454	1	5	1	4	1	2
9	32	4002	4051	1	2	1	1	1	2
9	37	204	203	1	3	1	1	1	3
9	43	2202	2252	1	4	1	3	1	2

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
9	45	304	353	1	4	1	4	1	2
9	46	2302	2354	1	1	1	1	1	1
9	49	1405	1455	2	6	2	5	1	1
8	12	2701	2751	1	1	1	1	1	1
8	37	202	251	1	2	1	1	1	2
8	40	4404	4451	1	1	1	1	1	1
8	42	4601	4651	1	1	1	1	1	1
8	42	4603	4602	1	2	1	1	1	2
8	47	1202	1251	1	2	1	1	1	2
8	48	4805	4852	1	2	1	2	1	1
8	49	1402	1453	1	5	1	3	1	2
7	17	2601	2651	1	1	1	1	1	1
7	34	4201	4252	1	3	1	2	1	2
7	34	4202	4251	1	1	1	1	1	1
7	35	203	253	1	4	1	3	1	2
7	37	202	252	1	3	1	2	1	1
7	39	1101	1153	1	7	1	3	1	1
7	40	4403	4451	1	1	1	1	1	1
7	40	4404	4452	1	2	1	2	1	2
7	42	4605	4651	1	3	1	2	1	2
7	43	2201	2251	1	4	1	3	1	2
7	44	102	152	1	4	1	3	1	1
7	45	302	353	2	5	2	3	1	1
7	46	2303	2302	1	2	1	1	1	2
7	49	1401	1453	1	3	1	3	1	1
7	49	1405	1452	1	3	1	2	1	1
6	32	4001	4051	1	1	1	1	1	1
6	35	201	252	1	3	1	2	1	2
6	35	203	251	1	2	1	1	1	2
6	35	203	254	1	4	1	3	1	1
6	36	1302	1352	1	2	1	2	1	1
6	37	203	252	1	2	1	2	1	1
6	39	1102	1153	1	5	1	3	1	2
6	39	1102	1155	1	7	1	4	1	2

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
6	41	4505	4551	1	2	1	2	1	1
6	44	104	151	1	3	1	3	1	1
6	46	2302	2351	1	2	1	1	1	2
6	46	2303	2353	2	5	2	5	1	1
6	46	2303	2355	4	8	4	7	1	2
6	47	1202	1255	2	8	2	5	1	1
6	47	1206	1255	1	15	1	7	1	2
6	49	1404	1454	1	3	1	3	1	1
5	34	4202	4252	1	2	1	2	1	1
5	34	4204	4253	1	7	1	4	1	1
5	35	201	253	1	4	1	3	1	1
5	37	203	253	1	3	1	3	1	2
5	39	1102	1151	1	1	1	1	1	1
5	41	4505	4504	1	1	1	1	1	1
5	42	4605	4652	1	4	1	3	1	1
5	44	101	153	2	4	2	4	1	1
5	44	104	150	1	2	1	2	1	1
5	46	2303	2351	1	4	1	3	1	1
5	47	1204	1203	1	2	1	1	1	2
5	48	4804	4852	1	2	1	2	1	1
5	49	1404	1455	1	7	1	5	1	2
5	49	1405	1451	1	2	1	1	1	2
5	49	1406	1405	1	2	1	2	1	1
5	49	1406	1452	1	3	1	3	1	1
4	33	4103	4152	1	2	1	2	1	1
4	34	4204	4251	1	4	1	2	1	1
4	35	203	252	1	3	1	2	1	2
4	35	206	254	1	1	1	1	1	1
4	36	1302	1353	1	2	1	2	1	1
4	39	1104	1155	2	4	2	4	1	1
4	43	2202	2251	1	3	1	2	1	1
4	43	2204	2203	1	1	1	1	1	1
4	46	2301	2354	1	1	1	1	1	1
4	49	1401	1455	1	4	1	3	1	1

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
4	49	1405	1453	1	4	1	3	1	1
4	49	1406	1453	1	4	1	4	1	1
3	32	4004	4051	1	7	1	2	1	4
3	32	4004	4052	2	12	2	3	1	5
3	33	4103	4151	1	1	1	1	1	1
3	34	4201	4253	3	5	2	3	1	2
3	34	4204	4252	2	6	2	3	1	2
3	35	201	251	1	1	1	1	1	1
3	37	202	253	1	4	1	3	1	2
3	37	202	254	1	4	1	4	1	1
3	37	203	254	1	4	1	4	1	1
3	37	206	254	1	5	1	4	1	2
3	39	1103	1151	1	1	1	1	1	1
3	39	1103	1153	1	2	1	2	1	1
3	39	1105	1154	1	3	1	3	1	1
3	40	4403	4452	2	2	1	2	1	2
3	42	4604	4602	1	1	1	1	1	1
3	43	2204	2202	1	2	1	1	1	2
3	44	101	152	1	3	1	3	1	1
3	44	102	153	3	6	3	4	1	2
3	45	304	302	1	1	1	1	1	1
3	45	304	351	1	2	1	2	1	1
3	45	304	352	2	3	2	3	1	1
3	47	1205	1251	1	2	1	2	1	1
3	47	1206	1205	1	4	1	2	1	3
3	49	1406	1402	1	1	1	1	1	1
2	18	2801	2851	1	1	1	1	1	1
2	32	4004	4003	1	3	1	1	1	3
2	33	4104	4103	1	2	1	1	1	2
2	34	4204	4203	1	3	1	1	1	3
2	36	1301	1351	1	1	1	1	1	1
2	37	203	251	1	1	1	1	1	1
2	37	205	252	1	4	1	4	1	1
2	37	205	253	1	5	1	5	1	1

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
2	37	206	251	2	2	1	2	1	2
2	38	4303	4351	1	1	1	1	1	1
2	39	1101	1154	2	4	2	4	1	1
2	39	1102	1154	4	4	3	4	1	1
2	39	1103	1152	2	2	2	2	1	1
2	39	1104	1151	1	1	1	1	1	1
2	39	1105	1152	1	1	1	1	1	1
2	42	4605	4602	1	1	1	1	1	1
2	45	304	354	3	4	3	4	1	1
2	45	305	304	1	1	1	1	1	1
2	45	306	305	1	1	1	1	1	1
2	46	2302	2352	1	2	1	2	1	1
2	47	1206	1251	2	6	2	3	1	2
2	47	1206	1252	3	7	3	4	1	1
2	47	1206	1253	4	10	4	5	1	3
2	47	1206	1254	5	13	5	6	1	3
1	33	4104	4151	3	3	2	2	1	1
1	33	4104	4152	4	4	3	3	1	1
1	35	201	254	1	1	1	1	1	1
1	35	205	204	1	1	1	1	1	1
1	35	205	251	2	2	2	2	1	1
1	35	205	252	1	1	1	1	1	1
1	36	1302	1351	1	1	1	1	1	1
1	36	1304	1302	2	2	1	1	2	2
1	37	205	203	1	1	1	1	1	1
1	37	205	204	2	2	2	2	1	1
1	37	205	251	3	3	3	3	1	1
1	37	206	203	1	1	1	1	1	1
1	37	206	252	3	3	3	3	1	1
1	38	4304	4351	1	1	1	1	1	1
1	38	4305	4351	1	1	1	1	1	1
1	39	1103	1154	1	1	1	1	1	1
1	39	1103	1155	3	3	3	3	1	1
1	39	1105	1104	1	1	1	1	1	1

No of Students	Game level	Image ID		No of attempts		No of unique attempts		No of repeated attempts	
		Given Step	Next Step	Min.	Max.	Min.	Max.	Min.	Max.
1	39	1105	1153	2	2	2	2	1	1
1	39	1106	1154	1	1	1	1	1	1
1	41	4505	4552	3	3	3	3	1	1
1	44	104	102	1	1	1	1	1	1
1	44	104	103	1	1	1	1	1	1
1	45	305	351	3	3	2	2	2	2
1	45	305	352	4	4	3	3	1	1
1	45	305	353	5	5	4	4	1	1
1	45	305	354	6	6	5	5	1	1
1	45	306	304	1	1	1	1	1	1
1	45	306	351	2	2	2	2	1	1
1	45	306	353	3	3	3	3	1	1
1	46	2304	2353	1	1	1	1	1	1
1	47	1201	1255	4	4	4	4	1	1
1	47	1205	1202	1	1	1	1	1	1
1	47	1206	1202	1	1	1	1	1	1
1	47	1207	1206	1	1	1	1	1	1
1	47	1207	1255	1	1	1	1	1	1
1	49	1402	1454	2	2	2	2	1	1
1	49	1405	1402	1	1	1	1	1	1
1	49	1406	1451	2	2	2	2	1	1
1	49	1407	1451	1	1	1	1	1	1
1	49	1407	1452	2	2	2	2	1	1
1	49	1407	1453	3	3	3	3	1	1
1	49	1407	1454	4	4	4	4	1	1
1	49	1407	1455	6	6	5	5	2	2